IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re application of: Vincent Fedele	Attorney Docket No.: IDTXP052B
Application No.: 10/561,647	Examiner: Unknown
Filed: June 21, 2004	Group: Unknown
Title: ACQUISITION OF HIGH RESOLUTION BIOMETRIC IMAGES	Confirmation No.: 7722

CERTIFICATE OF EFS-WEB TRANSMISSION
I hereby certify that this correspondence is being transmitted electronically through EFS-WEB to the Commissioner for Patents, P.O. Box 1450 Alexandria, VA 22313-1450 on July 21, 2008.

Signed: _____/Tara Hayden/_____
Tara Hayden

PETITION FOR APPLICATION BY OTHER THAN ALL THE INVENTORS
Pursuant to 37 C.F.R. §1.47 (a)

Commissioner of Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Dear Sir:

Applicants **John S. Berg, Christopher Butler, and Robert David Farraher** (the "remaining joint inventors") hereby petition the Commissioner to accept for application the above-identified U.S. Patent Application by other than all of the inventors.

The Declaration For Patent Application is attached in which the remaining joint inventors have signed on behalf of the omitted inventors as required by 37 C.F.R. §1.64 and M.P.E.P. §409.03(a), and it includes the last known address of the omitted inventor.

A Declaration of Facts in Support of Applying on Behalf of the Omitted Inventor is also attached and provides proof of the pertinent facts regarding the omitted inventor who refuses to sign as required by 37 C.F.R. §1.47(a) and M.P.E.P. §409.03(d).

In view of the refusal of the omitted inventor to sign the papers required for the above-identified application, the remaining joint inventors are believed to be entitled to make such an

application on behalf of and as agents for the omitted inventor. The required fee pursuant to 37 C.F.R. §1.17(g) is enclosed.

Dated: July 21, 2008

Respectfully submitted,
WEAVER AUSTIN VILLENEUVE & SAMPSON LLP

/Denise S. Bergin/

Denise S. Bergin
Registration No. 50,581

P.O. Box 70250
Oakland, CA 94612-0250

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re application of: Vincent Fedele	Attorney Docket No.: IDTXP052B
Application No.: 10/561,647	Examiner: Unknown
Filed: June 21, 2004	Group: Unknown
Title: ACQUISITION OF HIGH RESOLUTION BIOMETRIC IMAGES	Confirmation No.: 7722

DECLARATION OF FACTS IN SUPPORT OF APPLYING ON BEHALF OF OMITTED INVENTOR
Pursuant to 37 C.F.R. §1.47 (a)

Commissioner of Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Dear Sir:

This declaration is made as to the facts that are relied upon to establish the diligent effort made to secure the execution of the Declaration for the subject U.S. application by the omitted inventor, Vincent Fedele. This declaration is being made by the available person having first-hand knowledge of the facts recited therein.

I, Denise S. Bergin, do hereby declare:

1. The subject U.S. application is based on a Patent Cooperation Treaty (PCT) application flied on June 21, 2004 and having International Application No. PCT/US2004/019713.

2. All rights in and throughout the United States of America, its territories, and all foreign countries, in and to the invention described in the subject PCT application were assigned to Aprilis, Inc. ("Aprilis"). An Assignment was executed by all the inventors, including Vincent Fedele, and is was recorded in the U.S. Patent and Trademark Office (PTO). See attached Exhibit A.

3. The prior law firm representing Aprilis, Hamilton, Brook, Smith & Reynolds, P.C., forwarded, on March 6, 2006, a Declaration For Patent Application ("Declaration") to Mr. David A. Waldman at Aprilis for execution by all the inventors. See attached Exhibit B.

4. This Declaration was executed by all the inventors, except for Vincent Fedele. Apparently, prior to the time the Declaration was sent to Aprilis, Vincent Fedele had left Aprilis.

5. Some time in July 2006, responsibility for the subject U.S. application was transferred from Hamilton, Brook, Smith & Reynolds, P.C. to Beyer, Weaver & Thomas LLP, now Weaver, Austin, Villeneuve & Sampson LLP.

6. On June 4, 2008, I sent a copy of the PCT application along with a Declaration and Assignment to Vincent Fedele at his last known address. These documents were sent via Express Mail. I asked that Mr. Fedele return the executed Declaration and Assignment by June 20, 2008. The package was delivered on June 7, 2008, with a signature release for Mr. Fedele on file. See attached Exhibit C.

7. I have not received the signed Declaration or Assignment, or any other communication from Mr. Fedele.

8. Attached is a letter from Vincent Fedele dated July 27, 2006. This letter was sent in response to a request to execute a Declaration and Assignment for related US Application No. 10/561,646, which shares the same filing date and priority claim as the instant application. By this letter, Vincent Fedele indicated that he would not sign Declarations and Assignments nor review applications for subject matter invented during his time at Aprilis, unless he received compensation from Aprilis. See attached Exhibit D.

9. Mr. Fedele refused to sign a Declaration for related US Application No. 10/561,646. The remaining inventors submitted a petition pursuant to 37 C.F.R. §1.47 (a) accompanied by a Declaration of Facts by William J. Egan, III and including the letter from Mr. Fedele that is attached as Exhibit D. The petition was granted. See attached Exhibit E.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

/Denise S. Bergin/
Denise S. Bergin

July 21, 2008
Date

EXHIBIT A

UNITED STATES DEPARTMENT OF COMMERCE
Patent and Trademark Office
ASSISTANT SECRETARY AND COMMISSIONER
OF PATENTS AND TRADEMARKS
Washington, D.C. 20231

700152437A

FEBRUARY 15, 2005

PTAS

HAMILTON, BROOK, SMITH & REYNOLDS, P.C.
TIMOTHY J. MEAGHER
530 VIRGINIA ROAD, P.O. BOX 9133
CONCORD, MA 01742-9133

UNITED STATES PATENT AND TRADEMARK OFFICE
NOTICE OF RECORDATION OF ASSIGNMENT DOCUMENT

THE ENCLOSED DOCUMENT HAS BEEN RECORDED BY THE ASSIGNMENT DIVISION OF THE U.S. PATENT AND TRADEMARK OFFICE. A COMPLETE MICROFILM COPY IS AVAILABLE AT THE ASSIGNMENT SEARCH ROOM ON THE REEL AND FRAME NUMBER REFERENCED BELOW.

PLEASE REVIEW ALL INFORMATION CONTAINED ON THIS NOTICE. THE INFORMATION CONTAINED ON THIS RECORDATION NOTICE REFLECTS THE DATA PRESENT IN THE PATENT AND TRADEMARK ASSIGNMENT SYSTEM. IF YOU SHOULD FIND ANY ERRORS OR HAVE QUESTIONS CONCERNING THIS NOTICE, YOU MAY CONTACT THE EMPLOYEE WHOSE NAME APPEARS ON THIS NOTICE AT 703-308-9723. PLEASE SEND REQUEST FOR CORRECTION TO: U.S. PATENT AND TRADEMARK OFFICE, ASSIGNMENT DIVISION, BOX ASSIGNMENTS, CG-4, 1213 JEFFERSON DAVIS HWY, SUITE 320, WASHINGTON, D.C. 20231.

RECORDATION DATE: 02/08/2005

REEL/FRAME: 015685/0553
NUMBER OF PAGES: 5

BRIEF: ASSIGNMENT OF ASSIGNOR'S INTEREST (SEE DOCUMENT FOR DETAILS).
DOCKET NUMBER: 3174.1012-006

ASSIGNOR:
FEDELE, VINCENT

DOC DATE: 12/20/2004

ASSIGNOR:
BERG, JOHN S.

DOC DATE: 01/19/2005

ASSIGNOR:
BUTLER, CHRISTOPHER J.

DOC DATE: 12/14/2004

ASSIGNOR:
FARRAHER, ROBERT DAVID

DOC DATE: 12/14/2004

ASSIGNEE:
APRILIS, INC.
5 CLOCK TOWER PLACE
SUITE 200
MAYNARD, MASSACHUSETTS 01754

015685/0553 PAGE 2

SERIAL NUMBER:
PATENT NUMBER:
PCT NUMBER: US0019713
TITLE:

FILING DATE:
ISSUE DATE:

VIOLET MCCOY, EXAMINER
ASSIGNMENT DIVISION
OFFICE OF PUBLIC RECORDS

02/08/2005 700152637

RECORDATION FORM COVER SHEET
PATENTS ONLY

Docket No.: 3174.1012-006

To the Director of the U.S. Patent and Trademark Office: Please record the attached documents or the new address(es) below.

1. Name of conveying party(ies)/Execution Date(s):

1. VINCENT FEDELE
2. JOHN S. BERG
3. CHRISTOPHER J. BUTLER
4. ROBERT DAVID FARRAHER

Execution Date: 1) 12/20/04, 2) 1/19/05, 3,4) 12/14/04,

Additional name(s) of conveying party(ies) attached? [ ] Yes [X] No

2. Name and address of receiving party(ies)

Name: APRILIS, INC.

Internal Address:

Street Address: 5 CLOCK TOWER PLACE

SUITE 200

City: MAYNARD

State: MA

Country: USA Zip: 01754

Additional name(s) & address(es) attached? [ ] Yes [X] No

3. Nature of conveyance:

[X] Assignment [ ] Merger

[ ] Security Agreement [ ] Change of Name

[ ] Other

4. Application number(s) or patent number(s).

A. Parent Application No.(s)
PCT/US2004/019713

[ ] This document is being filed together with a new application.

B. Patent No.(s)

Additional numbers attached? [ ] Yes [X] No

5. Name and address of party to whom correspondence concerning document should be mailed:

Name: TIMOTHY J. MEAGHER

Internal Address:

Hamilton, Brook, Smith & Reynolds, P.C.

Street Address: 530 Virginia Road, P.O. Box 9133

City: Concord State: MA ZIP: 01742-9133

Phone No.: 978-341-0036 Fax No.: 978-341-0136

Email Address:

6. Total number of applications and patents involved: [1]

7. Total Fee (37 C.F.R. 3.41)..... $ 40

[ ] Enclosed

[X] Authorization to charge deposit account number 08-0380

[ ] Previously submitted - Doc. ID No. [ ]

[X] Authorized to charge any deficiencies or credit any overpayment to deposit account number 08-0380

Do not attach a copy of this page if paying by deposit account and filing via facsimile.

Attach a copy of this page if paying by deposit account and filing via mail

8. MARK B. SOLOMON
Name of Person Signing

Mark B Solomon
Signature

2/8/05
Date

Total number of pages including cover sheet, attachments, and document: [5]

OMB 0651-0027 (exp. 6/30/2005)

@PFDesktop\::ODMA/MHODMA/HBSR05;iManage;529533;1

REC RDATION FORM COVER SH ET
PATENTS ONLY

Docket No.: 3174.1012-006

To the Director of the U.S. Patent and Trademark Office: Please record the attached documents or the new address(es) below.

1. Name of conveying party(ies)/Execution Date(s):

1. VINCENT FEDELE
2. JOHN S. BERG
3. CHRISTOPHER J. BUTLER
4. ROBERT DAVID FARRAHER

Execution Date: 1) 12/20/04, 2) 1/19/05, 3,4) 12/14/04,

Additional name(s) of conveying party(ies) attached? [ ] Yes [X] No

3. Nature of conveyance:

[X] Assignment [ ] Merger

[ ] Security Agreement [ ] Change of Name

[ ] Other

2. Name and address of receiving party(ies)

Name: APRILIS, INC.

Internal Address:

Street Address: 5 CLOCK TOWER PLACE

SUITE 200

City: MAYNARD

State: MA

Country: USA Zip: 01754

Additional name(s) & address(es) attached? [ ] Yes [X] No

4. Application number(s) or patent number(s):

[ ] This document is being filed together with a new application.

A. Patent Application No.(s)

PCT/US2004/019713

B. Patent No.(s)

Additional numbers attached? [ ] Yes [X] No

5. Name and address of party to whom correspondence concerning document should be mailed:

Name: TIMOTHY J. MEAGHER

Internal Address:

Hamilton, Brook, Smith & Reynolds, P.C.

Street Address: 530 Virginia Road, P.O. Box 9133

City: Concord State: MA ZIP: 01742-9133

Phone No. 978-341-0036 Fax No. 978-341-0136

Email Address:

6. Total number of applications and patents involved: [1]

7. Total Fee (37 C.F.R. 3.41)..... $ 40

[ ] Enclosed

[X] Authorization to charge deposit account number 08-0380

[ ] Previously submitted - Doc. ID No. [ ]

[X] Authorized to charge any deficiencies or credit any overpayment to deposit account number 08-0380

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Attach a copy of this page if paying by deposit account and filing via mail.

8. MARK B. SOLOMON — Name of Person Signing

Mark B Solomon — Signature

2/8/05 — Date

Total number of pages including cover sheet, attachments, and document: [5]

Joint

ASSIGNMENT

WHEREAS, we, **Vincent Fedele, John S. Berg, Christopher J. Butler, and Robert David Farraher**, have invented a certain improvement in **Method and Apparatus for Processing Biometric Images** described in an application for Patent,

[ ] the specification of which is about to be filed in the United States Patent Office *(use for utility (37 CFR § 1.53(b)) and design filings only)*;

[ ] is about to be filed in the United States Patent Office as a Provisional Application;

[ ] the specification of which is United States Application No. [ ], filed [ ];

[X] the specification of which is a Patent Cooperation Treaty Application, International Application No. **PCT/US2004/019713**, filed **June 21, 2004**;

[ ] which was patented under United States Patent No. [ ].

WHEREAS, **Aprilis, Inc.** (hereinafter "ASSIGNEE"), a corporation organized and existing under the laws of the **State of Delaware**, and having a usual place of business at **5 Clock Tower Place, Suite 200, Maynard, MA 01754** desires to acquire an interest therein in accordance with agreements duly entered into with us;

NOW, THEREFORE, to all whom it may concern be it known that for and in consideration of said agreements and of other good and valuable consideration, the receipt of which is hereby acknowledged, we have sold, assigned and transferred and by these presents do hereby sell, assign and transfer unto said ASSIGNEE, its successors, assigns and legal representatives, the entire right, title and interest in and throughout the United States of America, its territories and all foreign countries, in and to said invention as described in said application, together with the entire right, title and interest in and to said application and such Letters Patent as may issue on said invention; said invention, application and Letters Patent to be held and enjoyed by said ASSIGNEE for its own use and behalf and for its successors, assigns and legal representatives, to the full end of the term for which said Letters Patent may be granted as fully and entirely as the same would have been held by us had this assignment and sale not been made; we hereby convey all rights arising under or pursuant to any and all international agreements, treaties or laws relating to the protection of industrial property by filing any such applications for Letters Patent. We hereby acknowledge that this assignment, being of the entire right, title and interest in and to said invention, carries with it the right in ASSIGNEE to apply for and obtain from competent authorities in all countries of the world any and all Letters Patent by attorneys and agents of ASSIGNEE's selection and the right to procure the grant of all such Letters Patent to ASSIGNEE for its own name as assignee of the entire right, title and interest therein;

AND, we hereby further agree for ourselves and our executors and administrators to execute upon request any other lawful documents and likewise to perform any other lawful acts which may be deemed necessary to secure fully the aforesaid invention to said ASSIGNEE, its successors, assigns and legal representatives, but at its or their expense and charges, including the execution of applications for patents in foreign countries, and the execution of any future

applications including substitution, reissue, divisional or continuation applications, and preliminary or other statements and the giving of testimony in any interference or other proceeding in which said invention or any application or patent directed thereto may be involved;

AND, we do hereby authorize and request each Patent Office and the Commissioner of Patents of the United States to issue such Letters Patent as shall be granted upon said invention to said ASSIGNEE, its successors, assigns, and legal representatives.

IN TESTIMONY WHEREOF, we have hereunto set our hands and affixed our seals the date set forth below.

Inventor's Signature: Vincent Fedele

Vincent Fedele

State/Commonwealth

of Massachusetts

County of Middlesex

On this 20 day of December, 2004, before me, the undersigned notary public, personally appeared **Vincent Fedele**,

☐ personally known to me, or

☑ proved to me through satisfactory evidence of identification, which was MA D-Lic Exp 1/24/08

to be the person whose name was signed on the foregoing instrument in my presence, and acknowledged that he/she signed the foregoing instrument as his/her free act and deed.

(SEAL) Colleen Beliveau Notary Public

Colleen Beliveau (print name) Colleen A. Beliveau
NOTARY PUBLIC
My Commission expires ____/____/____ My Commission expires Sept. 25 2009

Inventor's Signature: John S. Berg

John S. Berg

State/Commonwealth
of Massachusetts

County of Middlesex

On this 19th day of January, 2005, before me, the undersigned notary public, personally appeared **John S. Berg**,

☐ personally known to me, or

☑ proved to me through satisfactory evidence of identification, which was Massachusetts Drivers License

to be the person whose name was signed on the foregoing instrument in my presence, and acknowledged that he/she signed the foregoing instrument as his/her free act and deed.

(SEAL) Paula Caplan Notary Public

Paula Caplan (print name)

My Commission expires 04/12/07.

Inventor's Signature: Christopher J. Butler

Christopher J. Butler

State/Commonwealth
of Massachusetts

County of Middlesex

On this 14 day of December, 2004, before me, the undersigned notary public, personally appeared **Christopher J. Butler**,

☐ personally known to me, or

☑ proved to me through satisfactory evidence of identification, which was MA DLC

to be the person whose name was signed on the foregoing instrument in my presence, and acknowledged that he/she signed the foregoing instrument as his/her free act and deed.

(SEAL) Diane L. Tinelli Notary Public

DIANE L. TINELLI (print name)

My Commission expires 4/2/2010

Docket No. 3174.1012-006 PCT

Inventor's Signature: _____

Robert David Farraher

State/Commonwealth
of Massachusetts
County of Middlesex

On this 14 day of December, 2004, before me, the undersigned notary public, personally appeared **Robert David Farraher,**

☐ personally known to me, or

☑ proved to me through satisfactory evidence of identification, which was
MA LIC

to be the person whose name was signed on the foregoing instrument in my presence, and acknowledged that he/she signed the foregoing instrument as his/her free act and deed.

(SEAL) _____ Notary Public

DIANE L. TONELLI (print name)

My Commission expires 4/2/2010

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Confirmation Report–Memory Send

Time : Feb-08-05 03:50pm
Tel line 1 : 1-978-341-0242
Tel line 2 : 1-978-341-0242
Name : HBSR

Job number : 966

Date : Feb-08 03:48pm

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Document Pages : 06

Start time : Feb-08 03:48pm

End time : Feb-08 03:50pm

Pages sent : 06

Job number : 966 *** SEND SUCCESSFUL ***

HAMILTON, BROOK, SMITH & REYNOLDS, P.C.
530 Virginia Road, P.O. Box 9133
Concord, MA 01742-9133
Telephone: (978) 341-0036 Facsimile: (978) 341-0136

FACSIMILE COVER SHEET

Examiner: Assignment Division
U.S. Patent and Trademark Office

Date: February 8, 2005

Client Code: 3174

Facsimile No.: 703-306-5995

From: Mark B. Solomon

Subject:
Paper: Assignment Recordation
Docket No.: 3174.1012-006
Applicant: Aprilis, Inc.
Application No.: PCT/US2004/019713
Filing Date: June 21, 2004

Number of pages including this cover sheet: 6

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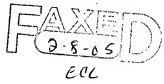
HAMI' 'ON, BROOK, SMITH & REYNOL' P.C.
530 Virginia Road, P.O. Box 9133
Concord, MA 01742-9133
Telephone: (978) 341-0036 Facsimile: (978) 341-0136

FACSIMILE COVER SHEET

Examiner: **Assignment Division**
U.S. Patent and Trademark Office



Date: February 8, 2005

Client Code: 3174

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From: Mark B. Solomon

Subject:

Paper:	Assignment Recordation
Docket No.:	3174.1012-006
Applicant:	Aprilis, Inc.
Application No.:	PCT/US2004/019713
Filing Date:	June 21, 2004

Number of pages including this cover sheet: 6

Please confirm receipt of facsimile: Yes X No ___

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FAX

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Voice Phone: 703-308-9723

To: Name: HAMILTON, BROOK, SMITH & REYNOLDS, P.C.
Company: TIMOTHY J. MEAGHER
Fax Number: 19783410242
Voice Phone:

Fax Notes:

Pg#	Description
1	Cover Page
2	276.TXT
4	Document 1, Batch 418830

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EXHIBIT B

HAMILTON
BROOK
SMITH &
REYNOLDS, P.C.

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P.O. BOX 9133
CONCORD, MA 01742-9133
TEL (978) 341-0036
FAX (978) 341-0136
www.hbsr.com

MUNROE H. HAMILTON
(1906-1984)

DAVID E. BROOK
JAMES M. SMITH
LEO R. REYNOLDS
JOHN L. DUPRÉ
DAVID J. BRODY
MARY LOU WAKIMURA
ALICE O. CARROLL
N. SCOTT PIERCE
SUSAN G. L. GLOVSKY
DORRIN M. HOGLE
ROBERT T. CONWAY
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ANNE J. COLLINS
TIMOTHY J. MEAGHER
STEVEN G. DAVIS
DEIRDRE E. SANDERS
BRIAN T. MORIARTY

PAUL G. ALLOWAY
THOMAS J. ARRIA
MICHAEL J. BADZINSKI
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H. JOON CHUNG
P. JAMES COE
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ROBERT H. UNDERWOOD
KEITH J. WOOD
MICHAEL M. YAMAUCHI

OF COUNSEL
ELIZABETH W. MATA
DARRELL L. WONG

PATENT AGENTS
SUSAN M. ABELLEIRA
ALEXANDER AKHIEZER
KAMILAH ALEXANDER
ERIC M. BALLOCY
MICHAEL GOTTSELIG
SUSAN C. KELLY
VIVIEN J. TANNOCH-MAGIN
PAMELA A. TORPEY

TECHNOLOGY SPECIALISTS
JOHN T. HURLEY
SARAH J. RODRIGUEZ
BOOYONG SHIM LIM
BENJAMIN J. SPARROW

MICHAEL KEWESHAN
ADMINISTRATIVE DIRECTOR

BARBARA J. FORGUE
ADMINISTRATOR OF
PATENT AND
TRADEMARK PRACTICE

March 6, 2006

David A. Waldman, Ph.D.
Vice President, Research and Development
Aprilis, Inc.
5 Clock Tower Place
Suite 200
Maynard, Massachusetts 01754

Re: U.S. National Stage Application No.: 10/561,647
Title: "Method and Apparatus for Processing Biometric Images"
HBSR Docket No.: 3174.1012-014

Dear David:

Enclosed is a Declaration for Patent Application for the referenced case and an Assignment form in which each inventor assigns rights to the invention to **Aprilis, Inc**.

It is appropriate at this time to confirm that we have designated the correct inventor(s) in the attached Declaration and that the specification and claims meet the enablement and best mode requirements under U.S. patent law.

To assist you in this determination, each inventor should note the following:

1. Inventorship: Only persons who have made an inventive contribution to the conception of at least one of the claims in the patent application should be listed as an inventor. Any doubts on this matter should be resolved with me before proceeding further.

2. Enablement: This requirement imposes an obligation on the inventor to describe the invention in sufficient detail to enable a person skilled in the art to make and use the invention

which is the subject of the patent application without undue experimentation.

3. Best Mode: The "best mode" requirement goes further than the "enablement" requirement by obligating the inventor to include in the patent application a description of the best mode contemplated by the inventor of practicing the invention.

An inventor's failure to comply with the "best mode" or "enablement" requirements may invalidate a patent. In addition, intentional failure to correctly name inventors could result in an invalid or unenforceable patent. If you have any questions or concerns, please call me.

Please note that the Declaration requires that each inventor carefully read the patent application in its entirety before signing it. If the application is acceptable, please have each inventor sign the Declaration in BLUE ink. Each inventor should also check to be sure that the typed name, address and citizenship on the Declaration are correct. If they are not, the inventor should indicate the correct information in BLUE ink, and initial and date each correction in the margin.

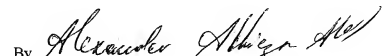
If you have any questions or concerns, or feel any changes need to be made in the Declaration, please call me.

The Assignment should be signed in BLUE ink by each inventor in the presence of a Notary Public.

Please return **all** pages of these documents as soon as possible for filing in the U.S. Patent and Trademark Office.

Very truly yours,

HAMILTON, BROOK, SMITH & REYNOLDS, P.C.

By 
Alexander Akhiezer

AA/saj
Enclosures

cc: Timothy J. Meagher, Esq.

DOCKET NO. 3174.1012-014

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Declaration for Patent Application

[ ] Supplemental (37 C.F.R. §1.67)

As a named inventor, I hereby declare that:

My residence, mailing address and citizenship are as stated next to my name;

I believe I am the original, first and sole inventor (if only one name is listed) or an original, first and joint inventor (if plural names are listed in the signatory page(s) commencing at page 2 hereof) of the subject matter which is claimed and for which a patent is sought on the invention entitled

METHOD AND APPARATUS FOR PROCESSING BIOMETRIC IMAGES

the specification of which (check one)

[ ] is attached hereto.

[ ] was filed on [ ] as United States Application Number [ ].

[X] was filed on June 21, 2004 as PCT International Application No. PCT/US2004/019713 and assigned United States Application No. 10/561,647.

[ ] and was amended on [ ] (if applicable).

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to patentability as defined in 37 C.F.R. §1.56, including for continuation-in-part applications, material information which became available between the filing date of the prior application and the national or PCT international filing date of the continuation-in-part application.

I hereby expressly authorize the filing of an International Patent Application under the Patent Cooperation Treaty which corresponds to and claims the priority of the above-identified application.

I hereby claim foreign priority benefits under 35 U.S.C. 119 or 365 of any foreign application(s) for patent or inventor's certificate, or of any PCT international application which designated at least one country other than the United States of America, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate, or of any PCT international application having a filing date before that of the application on which priority is claimed:

Prior Foreign Application(s)			Priority Not Claimed	Certified Copy Filed? YES	NO
(Number)	(Country)	(Day/Month/Year filed)	[ ]	[ ]	[ ]
(Number)	(Country)	(Day/Month/Year filed)	[ ]	[ ]	[ ]
(Number)	(Country)	(Day/Month/Year filed)	[ ]	[ ]	[ ]

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Full name of **sole** or **first** inventor: Vincent Fedele

Inventor's Signature: _____

Residence: City	State	Country	Citizenship
Harvard	MA	USA	USA

Mailing Address (Business or Residential)
Street or P.O. Box: P.O. Box 061

City	State	ZIP	Country
Harvard	MA	01451	USA

Full name of **second** joint inventor, if any: John S. Berg

Inventor's Signature: _____

Residence: City	State	Country	Citizenship
Franklin	MA	USA	USA

Mailing Address (Business or Residential)
Street or P.O. Box: 58 Jefferson Road

City	State	ZIP	Country
Franklin	MA	02038-3360	USA

Full name of **third** joint inventor, if any: Christopher J. Butler

Inventor's Signature: _____

Residence: City	State	Country	Citizenship
Arlington	MA	USA	USA

Mailing Address (Business or Residential)
Street or P.O. Box: 269 Broadway, Suite 9

City	State	ZIP	Country
Arlington	MA	02474	USA

Full name of **fourth** joint inventor, if any: Robert David Farraher

Inventor's Signature: _____

Residence: City	State	Country	Citizenship
Somerville	MA	USA	USA

Mailing Address (Business or Residential)
Street or P.O. Box: 24 Main Street, #2

City	State	ZIP	Country
Somerville	MA	02145	USA

Docket No. 3174.1012-014

Joint

ASSIGNMENT

WHEREAS, we, **Vincent Fedele, John S. Berg, Christopher J. Butler and Robert David Farraher**, have invented a certain improvement in **METHOD AND APPARATUS FOR PROCESSING BIOMETRIC IMAGES** described in an application for Patent,

[ ] the specification of which is about to be filed in the United States Patent Office *(use for utility (37 CFR § 1.53(b)) and design filings only)*;

[ ] is about to be filed in the United States Patent Office as a Provisional Application;

[ ] the specification of which is United States Application No. [ ], filed [ ];

[X] the specification of which is a Patent Cooperation Treaty Application, International Application No. **PCT/US2004/019713**, filed **June 21, 2004**, which designates the United States of America and assigned United States Application No. **10/561,647**;

[ ] which was patented under United States Patent No. [ ].

WHEREAS, **Aprilis, Inc.** (hereinafter "ASSIGNEE"), a corporation organized and existing under the laws of the **State of Delaware**, and having a usual place of business at **5 Clock Tower Place, Suite 200, Maynard, Massachusetts 01754** desires to acquire an interest therein in accordance with agreements duly entered into with us;

NOW, THEREFORE, to all whom it may concern be it known that for and in consideration of said agreements and of other good and valuable consideration, the receipt of which is hereby acknowledged, we have sold, assigned and transferred and by these presents do hereby sell, assign and transfer unto said ASSIGNEE, its successors, assigns and legal representatives, the entire right, title and interest in and throughout the United States of America, its territories and all foreign countries, in and to said invention as described in said application, together with the entire right, title and interest in and to said application and such Letters Patent as may issue on said invention; said invention, application and Letters Patent to be held and enjoyed by said ASSIGNEE for its own use and behalf and for its successors, assigns and legal representatives, to the full end of the term for which said Letters Patent may be granted as fully and entirely as the same would have been held by us had this assignment and sale not been made; we hereby convey all rights arising under or pursuant to any and all international agreements, treaties or laws relating to the protection of industrial property by filing any such applications for Letters Patent. We hereby acknowledge that this assignment, being of the entire right, title and interest in and to said invention, carries with it the right in ASSIGNEE to apply for and obtain from competent authorities in all countries of the world any and all Letters Patent by attorneys and agents of ASSIGNEE's selection and the right to procure the grant of all such Letters Patent to ASSIGNEE for its own name as assignee of the entire right, title and interest therein; I hereby expressly authorize the filing of an International Patent Application under the Patent Cooperation Treaty which corresponds to and claims the priority of the above-identified application;

AND, we hereby further agree for ourselves and our executors and administrators to execute upon request any other lawful documents and likewise to perform any other lawful acts which may be deemed necessary to secure fully the aforesaid invention to said ASSIGNEE, its successors, assigns and legal representatives, but at its or their expense and charges, including the execution of applications for patents in foreign countries, and the execution of any future applications including substitution, reissue, divisional or continuation applications, and preliminary or other statements and the giving of testimony in any interference or other proceeding in which said invention or any application or patent directed thereto may be involved;

AND, we do hereby authorize and request each Patent Office and the Commissioner of Patents of the United States to issue such Letters Patent as shall be granted upon said invention to said ASSIGNEE, its successors, assigns, and legal representatives.

IN TESTIMONY WHEREOF, we have hereunto set our hands and affixed our seals the date set forth below.

Inventor's Signature: _____

Vincent Fedele

State/Commonwealth

of _____

County of _____

On this _____ day of _____, 20____, before me, the undersigned notary public, personally appeared **Vincent Fedele**,

☐ personally known to me, or

☐ proved to me through satisfactory evidence of identification, which was

_____

to be the person whose name was signed on the foregoing instrument in my presence, and acknowledged that he/she signed the foregoing instrument as his/her free act and deed.

(SEAL) _____ Notary Public

_____ (print name)

My Commission expires ____/____/____

Inventor's Signature: _____

John S. Berg

State/Commonwealth

of _____

County of _____

On this _____ day of _____, 20____, before me, the undersigned notary public, personally appeared **John S. Berg**,

☐ personally known to me, or

☐ proved to me through satisfactory evidence of identification, which was

_____

to be the person whose name was signed on the foregoing instrument in my presence, and acknowledged that he/she signed the foregoing instrument as his/her free act and deed.

(SEAL) _____ Notary Public

_____ (print name)

My Commission expires _____/_____/_____

Inventor's Signature: _____

Christopher J. Butler

State/Commonwealth

of _____

County of _____

On this _____ day of _____, 20____, before me, the undersigned notary public, personally appeared **Christopher J. Butler**,

☐ personally known to me, or

☐ proved to me through satisfactory evidence of identification, which was

_____

to be the person whose name was signed on the foregoing instrument in my presence, and acknowledged that he/she signed the foregoing instrument as his/her free act and deed.

(SEAL) _____ Notary Public

_____ (print name)

My Commission expires _____/_____/_____

Inventor's Signature: _____

Robert David Farraher

State/Commonwealth

of _____

County of _____

On this _____ day of _____, 20____, before me, the undersigned notary public, personally appeared **Robert David Farraher,**

☐ personally known to me, or

☐ proved to me through satisfactory evidence of identification, which was

_____

to be the person whose name was signed on the foregoing instrument in my presence, and acknowledged that he/she signed the foregoing instrument as his/her free act and deed.

(SEAL) _____ Notary Public

_____ (print name)

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EXHIBIT C

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Weaver Austin IP Villeneuve Sampson

Intellectual Property Law

June 4, 2008 EB010862861US

Via Express Mail

Vincent A. Fedele
P.O. Box 061
Harvard, MA 01451

Re: U.S. Patent Application Entitled: ***"Method and Apparatus for Processing Biometric Images"***
Inventors: Fedele, et al. Application No: 10/561,647
Filing Date: December 20, 2005
Our File: IDTXP052B

Dear Mr. Fedele:

Enclosed is a copy of the above-identified patent application as filed with the U.S. Patent and Trademark Office. You may recall that the application was filed without having you sign the necessary documents (declaration and assignment forms) which need to be filed with the U.S. Patent and Trademark Office by June 20, 2008.

Accordingly, we are enclosing two documents: (i) a Declaration and Power of Attorney and (ii) an Assignment of rights to Aprilis, Inc. Before executing these documents, please ensure that you have reviewed and understand the contents of the enclosed patent application. Then, read, sign and date each of the enclosed documents adjacent to where your name appears, and return them to our office so that we may file them with the U.S. Patent and Trademark Office.

Finally, we would again like to remind you of our duty to disclose the most pertinent prior art of which you are aware to the Patent and Trademark Office. If you can think of any pertinent references or patents, or any similar existing technology, please let us know. The duty to disclose prior art continues until the patent actually issues. As such, if you become aware of other prior art in the future, please let us know.

Sincerely,
Weaver Austin Villeneuve & Sampson LLP

Denise S. Bergin

Cc: Tom McPherson
Corporate Counsel
Identix Incorporated
5600 Rowland Road
Minnetonka, MN 55343
Enclosures

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Denise S. Bergin
Wavier Austin Villeneuve & Sampson
500 12rh Street, Suite 200
Oakland, ca 94607

TO: (PLEASE PRINT) PHONE (

Vincent Fedele
P.O. Box 061
Harvard, MA 01451

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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Declaration for Patent Application

[ ] Supplemental (37 C.F.R. §1.67)

As a named inventor, I hereby declare that:

My residence, mailing address and citizenship are as stated next to my name;

I believe I am the original, first and sole inventor (if only one name is listed) or an original, first and joint inventor (if plural names are listed in the signatory page(s) commencing at page 2 hereof) of the subject matter which is claimed and for which a patent is sought on the invention entitled

METHOD AND APPARATUS FOR PROCESSING BIOMETRIC IMAGES

the specification of which (check one)

[ ] is attached hereto.

[ ] was filed on [ ] as United States Application Number [ ].

[X] was filed on June 21, 2004 as PCT International Application No. PCT/US2004/019713 and assigned United States Application No. 10/561,647.

[ ] and was amended on [ ] (if applicable).

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to patentability as defined in 37 C.F.R. §1.56, including for continuation-in-part applications, material information which became available between the filing date of the prior application and the national or PCT international filing date of the continuation-in-part application.

I hereby expressly authorize the filing of an International Patent Application under the Patent Cooperation Treaty which corresponds to and claims the priority of the above-identified application.

I hereby claim foreign priority benefits under 35 U.S.C. 119 or 365 of any foreign application(s) for patent or inventor's certificate, or of any PCT international application which designated at least one country other than the United States of America, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate, or of any PCT international application having a filing date before that of the application on which priority is claimed:

Prior Foreign Application(s)			Priority Not Claimed	Certified Copy Filed? YES	NO
(Number)	(Country)	(Day/Month/Year filed)	[ ]	[ ]	[ ]
(Number)	(Country)	(Day/Month/Year filed)	[ ]	[ ]	[ ]
(Number)	(Country)	(Day/Month/Year filed)	[ ]	[ ]	[ ]

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Full name of **sole or first** inventor: Vincent Fedele

Inventor's Signature: _____

Residence: City	State	Country	Citizenship
Harvard	MA	USA	USA

Mailing Address (Business or Residential)
Street or P.O. Box: P.O. Box 061

City	State	ZIP	Country
Harvard	MA	01451	USA

Full name of **second** joint inventor, if any: John S. Berg

Inventor's Signature: _____

Residence: City	State	Country	Citizenship
Franklin	MA	USA	USA

Mailing Address (Business or Residential)
Street or P.O. Box: 58 Jefferson Road

City	State	ZIP	Country
Franklin	MA	02038-3360	USA

Full name of **third** joint inventor, if any: Christopher J. Butler

Inventor's Signature: _____

Residence: City	State	Country	Citizenship
Arlington	MA	USA	USA

Mailing Address (Business or Residential)
Street or P.O. Box: 269 Broadway, Suite 9

City	State	ZIP	Country
Arlington	MA	02474	USA

Full name of **fourth** joint inventor, if any: Robert David Farraher

Inventor's Signature: _____

Residence: City	State	Country	Citizenship
Somerville	MA	USA	USA

Mailing Address (Business or Residential)
Street or P.O. Box: 24 Main Street, #2

City	State	ZIP	Country
Somerville	MA	02145	USA

Joint

ASSIGNMENT

WHEREAS, we, **Vincent Fedele, John S. Berg, Christopher J. Butler and Robert David Farraher**, have invented a certain improvement in **METHOD AND APPARATUS FOR PROCESSING BIOMETRIC IMAGES** described in an application for Patent,

[ ] the specification of which is about to be filed in the United States Patent Office *(use for utility (37 CFR § 1.53(b)) and design filings only)*;

[ ] is about to be filed in the United States Patent Office as a Provisional Application;

[ ] the specification of which is United States Application No. [ ], filed [ ];

[X] the specification of which is a Patent Cooperation Treaty Application, International Application No. **PCT/US2004/019713**, filed **June 21, 2004**, which designates the United States of America and assigned United States Application No. **10/561,647**;

[ ] which was patented under United States Patent No. [ ].

WHEREAS, **Aprilis, Inc.** (hereinafter "ASSIGNEE"), a corporation organized and existing under the laws of the **State of Delaware**, and having a usual place of business at **5 Clock Tower Place, Suite 200, Maynard, Massachusetts 01754** desires to acquire an interest therein in accordance with agreements duly entered into with us;

NOW, THEREFORE, to all whom it may concern be it known that for and in consideration of said agreements and of other good and valuable consideration, the receipt of which is hereby acknowledged, we have sold, assigned and transferred and by these presents do hereby sell, assign and transfer unto said ASSIGNEE, its successors, assigns and legal representatives, the entire right, title and interest in and throughout the United States of America, its territories and all foreign countries, in and to said invention as described in said application, together with the entire right, title and interest in and to said application and such Letters Patent as may issue on said invention; said invention, application and Letters Patent to be held and enjoyed by said ASSIGNEE for its own use and behalf and for its successors, assigns and legal representatives, to the full end of the term for which said Letters Patent may be granted as fully and entirely as the same would have been held by us had this assignment and sale not been made; we hereby convey all rights arising under or pursuant to any and all international agreements, treaties or laws relating to the protection of industrial property by filing any such applications for Letters Patent. We hereby acknowledge that this assignment, being of the entire right, title and interest in and to said invention, carries with it the right in ASSIGNEE to apply for and obtain from competent authorities in all countries of the world any and all Letters Patent by attorneys and agents of ASSIGNEE's selection and the right to procure the grant of all such Letters Patent to ASSIGNEE for its own name as assignee of the entire right, title and interest therein; I hereby expressly authorize the filing of an International Patent Application under the Patent Cooperation Treaty which corresponds to and claims the priority of the above-identified application;

AND, we hereby further agree for ourselves and our executors and administrators to execute upon request any other lawful documents and likewise to perform any other lawful acts which may be deemed necessary to secure fully the aforesaid invention to said ASSIGNEE, its successors, assigns and legal representatives, but at its or their expense and charges, including the execution of applications for patents in foreign countries, and the execution of any future applications including substitution, reissue, divisional or continuation applications, and preliminary or other statements and the giving of testimony in any interference or other proceeding in which said invention or any application or patent directed thereto may be involved;

AND, we do hereby authorize and request each Patent Office and the Commissioner of Patents of the United States to issue such Letters Patent as shall be granted upon said invention to said ASSIGNEE, its successors, assigns, and legal representatives.

IN TESTIMONY WHEREOF, we have hereunto set our hands and affixed our seals the date set forth below.

Inventor's Signature: _____

Vincent Fedele

State/Commonwealth

of _____

County of _____

On this _____ day of _____, 20_____, before me, the undersigned notary public, personally appeared **Vincent Fedele**,

☐ personally known to me, or

☐ proved to me through satisfactory evidence of identification, which was _____

to be the person whose name was signed on the foregoing instrument in my presence, and acknowledged that he/she signed the foregoing instrument as his/her free act and deed.

(SEAL) _____ Notary Public

_____ (print name)

My Commission expires _____/_____/_____

EXHIBIT C
(part 2)

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
6 January 2005 (06.01.2005)

PCT

(10) International Publication Number
WO 2005/001752 A2

(51) International Patent Classification[7]: G06K 9/00

(21) International Application Number:
PCT/US2004/019713

(22) International Filing Date: 21 June 2004 (21.06.2004)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:

60/480,008	21 June 2003 (21.06.2003)	US
60/519,792	13 November 2003 (13.11.2003)	US
60/523,068	18 November 2003 (18.11.2003)	US

(71) Applicant (*for all designated States except US*): APRILIS, INC. [US/US]; 5 Clock Tower Place, Suite 200, Maynard, MA 01754 (US).

(72) Inventors; and

(75) Inventors/Applicants (*for US only*): FEDELE, Vincent [US/US]; Post Office Box 061, Harvard, MA 01451 (US). BERG, John, S. [US/US]; 58 Jefferson Road, Franklin, MA 02038 (US). BUTLER, Christopher, J. [US/US]; Suite 9, 269 Broadway, Arlington, MA 02474 (US). FARRAHER, Robert, David [US/US]; 24 Main Street #2, Somerville, MA 02145 (US).

(74) Agents: MEAGHER, Timothy, J. et al.; Hamilton, Brook, Smith & Reynolds, P.C., 530 Virginia Road, P.O. Box 9133, Concord, MA 01742-9133 (US).

(81) Designated States (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

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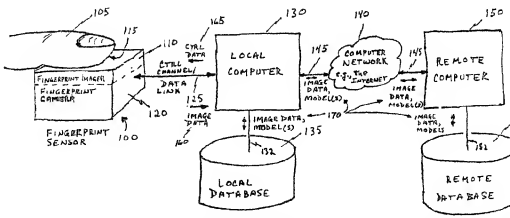
For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: METHOD AND APPARATUS FOR PROCESSING BIOMETRIC IMAGES



(57) Abstract: A method and apparatus for applying gradient edge detection to detect features in a biometric, such as a fingerprint, based on data representing an image of at least a portion of the biometric. The image is modeled as a function of the features. Data representing an image of the biometric is acquired, and features of the biometric are modeled for at least two resolutions. The method and apparatus improves analysis of both high-resolution images of biometrics of friction ridge containing skin that include resolved pores and lower resolution images of biometrics without resolved pores.

WO 2005/001752 A2

METHOD AND APPARATUS FOR PROCESSING BIOMETRIC IMAGES

RELATED APPLICATION(S)

This application claims the benefit of U.S. Provisional Application No. 60/480,008, filed on June 21, 2003, U.S. Provisional Application No. 60/519,792, filed on November 13, 2003, and U.S. Provisional Application No. 60/523,068, filed on November 18, 2003. This application is related to PCT Application entitled "Acquisition of High Resolution Biometric Images," filed concurrently herewith on June 21, 2004 under Attorney Docket No. 3174.1012-004. The entire teachings of the above applications are incorporated herein by reference.

BACKGROUND OF THE INVENTION

Growing concerns regarding domestic security have created a critical need to positively identify individuals as legitimate holders of credit cards, driver's licenses, passports and other forms of identification. The ideal identification process is reliable, fast, and relatively inexpensive. It should be based on modern, high-speed, electronic devices that can be networked to enable fast and effective sharing of information. It should also be compact, portable, and robust for convenient use in a variety of environments, including airport security stations, customs and border crossings, police vehicles, point of sale applications, credit card and ATM applications, home and office electronic transactions, and entrance control sites to secure buildings.

A well established method for identification or authentication is to compare biometric characteristics of an individual with a previously obtained authentic biometric of the individual. Possible biometric characteristics include ear shape and

structure, facial characteristics, facial or hand thermograms, iris and retina structure, handwriting, and friction ridge patterns of skin such as fingerprints, palm prints, foot prints, and toe prints. A particularly useful biometric system uses fingerprints for individual authentication and identification. (Maltoni, Maio, Jain, and Prabhakar, "Handbook of Fingerprint Recognition", Springer, 2003, chapter 1, and David R. Ashbaugh, "Quantitative-Qualitative Friction Ridge Analysis", CRC Press, 1999).

Fingerprints have traditionally been collected by rolling an inked finger on a white paper card. Since this traditional process clearly fails to meet the criteria listed above, numerous attempts have been made to develop an electronically imaged fingerprint method to address new security demands. These modern methods typically use, as a key component, a solid-state device such as a capacitive or optical sensor to capture the fingerprint image in a digital format. By using a solid-state imager as part of a fingerprint identification apparatus, a fingerprint can be collected conveniently and rapidly during a security check, for example, and subsequently correlated, in near real-time, to previously trained digital fingerprints in an electronic database. The database can reside on a computer at the security check point, on a secure but portable or removable storage device, on a remotely networked server, or as a biometric key embedded into a smartcard, passport, license, birth certificate, or other form of identification.

The topological features of a typical finger comprise a pattern of ridges separated by valleys, and a series of pores located along the ridges. The ridges are typically 100 to 300 μm wide and can extend in a number of different swirl-like patterns for several mm to one or more cm. The ridges are separated by valleys with a typical ridge-valley period of approximately 250-500 μm. Pores, roughly circular in cross section, range in diameter from about 40 μm to 200 μm, and are aligned along the ridges. The patterns of both ridges/valleys and pores are believed to be unique to each fingerprint. No currently available commercial fingerprint acquisition technique is able to resolve pores and ridge deviation details to a degree necessary to use this vastly larger amount of information as a biometric key.

Accordingly, present-day automatic fingerprint identification procedures use only portions of ridge and valley patterns, called minutiae, such as ridge ending-points, deltoids, bifurcations, crossover points, and islands, which are found in almost every

fingerprint (Maltoni, Maio, Jain, and Prabhakar, "Handbook of Fingerprint Recognition", Springer, 2003, chapter 3). Extraction and comparison of minutiae is the basis of most current automatic fingerprint analysis systems.

There are several important limitations with minutiae-based methods of automatic fingerprint analysis. In order to collect enough minutiae for reliable analysis a relatively large area, at least 0.50 x 0.50 inches, good quality, fingerprint, or latent image of a fingerprint must be available. Large prints are often collected by rolling an inked finger on a white card, and subsequently scanning the inked image into an electronic database. This manual procedure is an awkward and time consuming process that requires the assistance of a trained technician. Automated methods for collecting large fingerprints usually require mechanically complicated and expensive acquisition devices. Large area fingerprints suffer from distortions produced by elastic deformations of the skin so that the geometrical arrangements between minutiae points vary from image to image of the same finger, sometimes significantly. In addition, forensic applications can involve small, poor quality, latent prints that contain relatively few resolved minutiae so that reliable analysis based on a limited number of minutiae points is quite difficult.

Minutiae comparison ignores a significant amount of structural information that may be used to enhance fingerprint analysis. Since the typical fingerprint contains between 7 to 10 times as many pores as minutiae, techniques that include both pores and minutiae should greatly improve matching compared to techniques that use only minutiae. This highly detailed information is referred to in the industry as "level three detail," and is the basis of most forensic level analysis of latent images left at a crime scene, where the latent does not contain enough minutiae to make an accurate identification. Stosz and Alyea (J. D. Stosz, L. A. Alyea, "Automated system for fingerprint authentication using pores and ridge structures", Proc. SPIE, vol 2277, 210-223, 1994) have confirmed this expectation by showing that the use of pores combined with minutiae improves the accuracy of fingerprint matching and allows successful analysis of relatively small prints. Their image sensor used a common prism-based configuration, a high-resolution Charge Coupled Device (CCD) video camera, and a macro lens to provide the resolution needed to image pores. After acquisition, the gray-scale images are converted to a binary

format and then processed further to produce a skeleton image from which minutiae and pores are identified. Fingerprints are compared by independent correlations between pores and minutiae extracted from the various images.

SUMMARY OF THE INVENTION

There is a need for a procedure that improves an analysis of both high-resolution images of biometrics (e.g., fingerprints that include resolved pores) and lower resolution images of biometrics (e.g., fingerprints without resolved pores). The principles of the present invention fulfill this need by using identifying information in a biometric, which, in the case of a fingerprint, can include fingerprint ridge shapes or profiles in addition to usual ridge contours and the position, shape, and sizes of pores. Images to be analyzed may include biometric images, such as fingerprints, (i) from an apparatus custom-designed to capture such images either in real-time or non-real-time, or (ii) from other apparatus (e.g., computer scanner) that scans crime scene latent images, as well as existing criminal arrest or civil-applicant background check records.

Accordingly, one embodiment of the principles of the present invention includes a method and apparatus for processing an image of a biometric, which, for purposes of illustration only, is described in detail herein in reference to acquiring and processing an image of a fingerprint. The method and apparatus, referred to generally here as "system," may apply a gradient edge detection process to detect features in a biometric based on data representing an image of at least a portion of the fingerprint. The system models the image as a function of the fingerprint features, which may include level three features. The models may be referred to herein as "trained" models.

The system may construct a model for at least two resolutions: a low resolution "outline" model and a high resolution "details" model. The outline model may generally show an edge topology of ridge features; the details model generally shows edge topology and specific ridge deviations and locations and sizes of pores. The system may also construct a model for a third resolution, a "fine details" model. The fine details model is used for precisely defining and locating particular biometric features more accurately than at the low or high resolutions, such as pores

in a fingerprint image. It is this third resolution model that is used, for example, for pore matching in authentication and identification processes in a fingerprint application.

In constructing the model of a fingerprint, the system may identify, outline, and extract ridge deviation detail and pore features. The ridge deviation detail may include ridge contours, including scars, and the pore features may include position, shape, and sizes of pores.

Biometrics for which the system is adapted to acquire, model, preprocess, and process may include: ear shape and structure, facial or hand thermograms, iris or retina structure, handwriting, and friction ridge patterns of skin such as fingerprints, palm prints, foot prints, and toe prints.

The system may construct models at various resolution levels through a process of binning the original image data. In this process, the image data is divided into equal-sized, sub arrays of pixels. Each pixel sub array is subsequently represented in the model by a single pixel whose value is equal to the average pixel value in the corresponding sub array. The sizes of the sub arrays can be adjusted by a user of the software to any appropriate value; typical examples follow for a CMOS or CCD sensor array, described below in reference to Fig. 4, and having an array of 1024 x 1280 6 μm square pixels. "Outline" resolution models may be constructed with a sub-arrays having a relatively large numbers of pixels, for example 10 to 15, "details" resolution models may be constructed with sub arrays having a relatively small number of pixels, for example 5 to 10, and "fine details" models may be constructed with sub-arrays having even fewer pixels, for example 2 to 5. The fine details model may be used to locate and define particular biometric features more accurately than at the low or high resolution; for example, in the case of fingerprints, pores on ridges may be located and defined in the fine details model.

The gradient determined by the gradient edge detection process may be estimated for each pixel of the model after applying a noise filter to the image. The detection process may use a finite-differences process. The detection process may also include a series of steps, such as the following: (a) after calculating the gradients, identifying and marking an image point as an edge point having a locally maximal gradient in the direction of the gradient that exceeds a threshold; (b)

identifying neighboring edge points by finding nearest pixels to the original edge point that lie in a direction that is approximately perpendicular to the gradient direction that passes through the first edge point; (c) for the nearest pixels, determining gradient values and, for the pixel with a gradient that is maximal along its gradient direction and has a value that exceeds a threshold, assigning the pixel to be the next edge point; (d) continuing either until the edge is terminated or the edge closes with itself to form a continuous curve; (e) terminating the process at the previously determined edge point if the gradient of a candidate edge point is less than the threshold; and (f) repeating the process until all potential edge points have been considered.

The system may automatically distinguish biometric features from noise. In one embodiment, the noise is defined as features that have less than a minimum width or extend less than a minimum distance. In addition to automatically distinguishing the biometric features from noise, the system may also support manual editing of features and/or manual selection of features that must be present for a successful match.

The system may model multiple regions of a single image of the portion of the biometric. For example, the models may be models of five regions of the biometric, such as four quadrants of the biometric with small overlaps in each quadrant, and may also include a center portion that overlaps portions of each of the four quadrants. The system may allow a user to add, extend, or delete features and may allow a user to identify specific or unique features that must be present for a match. The system may also allow a user to adjust the size or position of the model(s) relative to the biometric. User interaction may be performed through a Graphical User Interface (GUI) supported by the system.

A useful aspect of this technique for edge detection is an ability to detect edges even if a portion or all of the image is significantly over and/or underexposed, as a few levels of gray difference are sufficient to determine a location of an edge. This allows for highly accurate matching even if the incoming image or portion of the image for comparison is not properly exposed, which allows for minimal or no exposure correction.

The image may be a previously stored image, and the system may normalize the scale or size of the previously stored image so that the scale is similar to that of the trained model(s). This scaling calibration also allows highly accurate measurements to be taken for forensic purposes. Typical accuracy of such measurements may be better than 10um.

In the case where the biometrics are fingerprints, the fingerprint features may include ridge structure with ridge deviation detail. Further, for fingerprints and other biometrics, the system may display the image to a user with an overlay of indications of the biometric features on the image or filtered biometric features according to a selectable criteria. Also, the system may automatically rotate the image to a specified orientation for displaying to a user and can rotate and scale the image while performing a match. In one embodiment, the image is a gray-scale image, and the gradient edge detection process is a gray-scale gradient edge detection process.

The system may also include a database and add the image of a biometric or portion thereof to the database. The system may store the image and the model of the image in the database. The image may be stored at full sampled resolution in the database or be compressed prior to being stored in the database. Preferably, if the image is compressed, the system compresses it in a lossless manner. The model may also be compressed prior to being stored in the database. The system may also encrypt the data or the model prior to storing them in the database.

The system may also store additional information with the image and/or model in the database. For example, the associated information may include at least one of the following: identity of a person associated with the biometric; manufacturer, model, or serial number of the instrument supplying the data representing the biometric; the date and/or time of imaging the biometric; calibration data associated with the instrument used to acquire the biometric; temperature at the time the image was acquired; unique computer ID of the computer receiving image data from the instrument acquiring the image of the biometric; or name of person logged onto the computer at the time the image was acquired. The associated information may also include a photograph, voice recording, or signature of the person whose biometric is imaged. The associated information may also be a

watermark, where the watermark may be identifying information (e.g., associated information as described above) or anti-tampering information to determine whether the image and/or model has been compromised. If compromised, the image and model are typically marked or removed from the database.

The system may also include techniques for authenticating and/or identifying the person whose biometric is acquired. For example, the system may compare a previously stored model from a database to a present image, where the biometric is of a person having a known identity or an unknown identity. A "previously stored model" may be a model that has been stored, for example in a local or remote database, or is a model of a previously acquired image that has not been stored per se Similar usage of the "previously stored image" also applies herein. The present image may be a live image, an image previously stored in a local or remote database, a scanned image, or an image from another source, e.g., the National Institute of Standards and Technology (NIST) or Federal Bureau of Investigation (FBI) database. The system may compare the biometric features in at least two steps: comparing outline features and, if a candidate match is determined, comparing details features, and, if still a candidate match, then comparing pore features. In comparing outline features, the system may compare outline features of the previously stored model to outline features of the present image to determine (i) whether the present image is a candidate for a match or (ii) whether the previously stored model is a candidate for a match. In comparing the outlines features, the system may determine whether the comparison exceeds a predetermined candidate threshold. If the present image is not a candidate for a match, the system may compare outline features of a next previously stored model to the outline features of the present image to determine whether the present image is a candidate for a match and use the next previously stored model for details comparison if it is a match. If the previously stored model is not a candidate for a match, the system may compare outline features of a next previously stored model to the outline features of the present image to determine whether the next previously stored model is a candidate for a match and, if it is a match, the system may use the next previously stored model for details comparison.

If the system determines a candidate match of outlines features is found, the system may compare details features of the previously stored model with detailed features of the present image. The system may compare the details features by determining whether the details comparison exceeds a predetermined threshold or may determine whether required features associated with the previously stored model are found in the present image. In the case of biometrics related to friction ridge containing skin, the system may also determine whether pore features in the previously stored model are found in the present image. If so, the system may indicate which pores in the previously enrolled (i.e., acquired and modeled) image appear in the expected location in the present image, including allowance for distortions that normally occur between successive impressions, and may also show a pore count or a statistical probability of an error in such a match. The system, in comparing the outline, details, required details, and pore features, may determine whether the comparison meets a predetermined level of a number of consecutive frames in which the various features thresholds have been met, in order to call the comparison a match. The individual details and/or pores from successive frames need not be the same details and pores (unless specified as required) but could be different, but also exceeding the threshold(s). Further, the system may select another previously stored model for correlating with the feature set of the present image, and a successful match declared if any model or models exceed the threshold(s).

The system may also scale and/or rotate the previously stored model(s) present image, or model of the present image for use in comparing the two.

The system may also adaptively adjust the previously stored model(s) to account for variability associated with recording or acquiring the present image due to elasticity of the skin. For example, the variability may include stretching of the fingerprint, or portions thereof, laterally, longitudinally, or radially. The variability may also be caused by pressure of the fingerprint on a medium used to record or acquire the present image. In addition, this adaptive conformity may also take into account an expected location of ridge deviation details and, optionally, pore details.

The system may also compare the previously stored model against multiple present images until a match is found or comparison with the multiple present images is complete. In another embodiment, the system may compare multiple

previously stored models against the present image until a match is found or comparison with the multiple previously stored models is complete. In yet another embodiment, the system may compare multiple previously stored models against multiple present images until a match is found or comparison among the multiple present images and the multiple previously stored models is complete.

In some embodiments, the present image includes multiple fingerprints of an individual. For example, between two and ten fingerprint images of an individual may be captured and modeled.

The system may also provide for preprocessing of the data representing the image. The preprocessing may include subsampling the image to capture the data. The preprocessing may also include decimating the data representing the image, where decimating may include removing every other row and every other column of the data. The system may also preprocess the data by binning the data, which includes averaging multiple "nearby" pixels to reduce the data to a predetermined size. The system may also correct for uneven imaging of the fingerprint, sometimes referred to as "flattening the field." Flattening the field compensates for light source properties, optics variations, Holographic Optical Element (HOE) variations, and differences among the gain and/or offsets of the pixels in a sensor array used to image the fingerprint. The system may also account for defective pixels in the sensor array, for example, by averaging pixel values around a defective pixel to determine a corrected intensity value of the defective pixel. The location and description of defective pixels may be provided by the manufacturer of the sensor array or measured during sensor assembly and stored in system memory for use during calibration of the fingerprint sensor.

The preprocessing may also include encrypting the data representing the image. The preprocessing may also include changing the image orientation, such as horizontal or vertical flip and rotation, or a combination of the two. The system may also apply a watermark to the data representing the image or the system may attach acquire information, such as information about the instrument acquiring the image representing the biometric, to the data representing the image. The watermark may contain information and also may be used as a tamper-proofing technique, ensuring that a modified image is identified or not allowed to be used.

Another embodiment of the system according to the principles of the present invention includes an acquisition unit that acquires data representing an image of a biometric. The acquisition may be a biometric sensor to acquire live scan images, a photograph scanner to scan paper prints of biometrics, a computer modem to receive data from a database of biometric images, or other electronic medium performing similar functions. The system also includes a modeler that models features of the fingerprint utilizing at least two levels of image resolution.

Various example embodiments of the instrument used to acquire images of biometrics are described herein. The embodiments may also include alternative embodiments, such as those disclosed in a related application, entitled "Acquisition of High Resolution Biometric Images," Attorney Docket No. 3174.1012-004, being filed concurrently herewith. The entire teachings of the related application are incorporated herein by reference.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other objects, features and advantages of the invention will be apparent from the following more particular description of preferred embodiments of the invention, as illustrated in the accompanying drawings in which like reference characters refer to the same parts throughout the different views. The drawings are not necessarily to scale, emphasis instead being placed upon illustrating the principles of the invention.

Fig. 1 is a computer network in which a fingerprint sensor according to the principles of the present invention is deployed;

Fig. 2 is a system hierarchical diagram of the fingerprint sensor of Fig. 1;

Fig. 3A is a high level schematic diagram of the fingerprint sensor of Fig. 1;

Fig. 3B is a detailed schematic diagram of the fingerprint sensor of Fig. 1;

Fig. 4 is a generalized mechanical diagram of an imager in the fingerprint sensor of Fig. 1;

Fig. 5 is an electrical schematic diagram of camera electronics in a camera of the fingerprint sensor of Fig. 1;

Fig. 6A is a hierarchical diagram of a local computer used in the computer network of Fig. 1;

Fig. 6B is a block diagram of example software executed in the local computer of Fig. 1;

Fig. 7 is a flow diagram of a process associated with acquiring and processing of the fingerprint image data acquired by the fingerprint sensor of Fig. 1;

Fig. 8 is a high level block diagram of example processing elements operating in the computer network of Fig. 1 for processing the acquired fingerprint images;

Fig. 9 is an image of a portion of a fingerprint acquired by the fingerprint sensor of Fig. 1;

Fig. 10 is the image of Fig. 9 with an overlay of outline features of fingerprint ridges;

Fig. 11 is the image of Fig. 9 with a subset of the fingerprint overlaid with detail features of the fingerprint ridges and deviations;

Fig. 12 is a zoomed-in image of the portion of overlaid features of Fig. 11;

Fig. 13 is a flow diagram of a fingerprint enrollment process executed by the enrollment software of Fig. 6B;

Fig. 14 is a flow diagram of acquisition software of Figs. 6B and 13;

Fig. 15 is a flow diagram of a process for constructing a model of the fingerprint acquired by the processes of Figs. 13 and 14;

Fig. 16 is a flow diagram of fingerprint verification that is part of the analysis software of Fig. 6B;

Fig. 17A-17C are flow diagrams of a matching processes beyond the outlines level executed by the fingerprint verification process of Fig. 16;

Fig. 18 is a flow diagram of a fingerprint feature correlation process executed by the processes of Figs. 16 and 17;

Fig. 19 is flow diagram of an adaptive conformity process executed by the fingerprint feature correlation process of Fig. 18; and

Figs. 20A and 20B are diagrams including a set of pixels in the sensor array of Fig. 3A that illustrates preprocessing for correcting bad pixels.

DETAILED DESCRIPTION OF THE INVENTION

A description of preferred embodiments of the invention for a fingerprint biometric follows. It should be understood that the principles of the present invention and example preferred embodiments of the methods and apparatus described below may be applied to other biometrics, including: ear shape and structure, facial or hand thermograms, iris or retina structure, handwriting, and friction ridge patterns of skin such as fingerprints, palm prints, foot prints, and toe prints

In general, the principles of the present invention include a procedure that is capable of identifying highly detailed fingerprint features by using gradient edge detection techniques at several image resolutions. The procedure identifies and traces edges of structural features to outline ridges and pores. At sufficiently high resolution, referred to in the industry as "level three details," the ridge outlines contain thousands of structural features that can be used in fingerprint matching. This capability improves matching reliability over systems that reduce ridge patterns to a few minutiae types or systems that consider ridges only as simple contour lines, via a process known as binarization or thinning. Because of the richness of features in fingerprints at high resolution, the procedure also allows for reliable matching of small portions or fragments of prints. In a preferred embodiment, edge detection software is combined with high resolution image acquisition technology that is capable of resolving pores and ridge profiles.

Fig. 1 is a system diagram in which an embodiment of a fingerprint sensor 100 according to the principles of the present invention is employed. The fingerprint sensor 100 includes a fingerprint imager 110 and fingerprint camera 120. The imager 110 and camera 120 may be mechanically, electrically, and optically connected in a single "box." A finger 105 is placed on the fingerprint imager 110 at a "viewable" location by the imager 110 for acquisition of a fingerprint 115 by the camera 120 and for modeling of the fingerprint 115 by processing as described hereinbelow.

For many reasons, it is useful to design the fingerprint sensor 100 in as small a package as possible, such as for use in field operations, security systems, and other applications. However, although packaged in a small size, the fingerprint imager

110 and camera 120 are preferably designed in such a manner as to capture an image of the fingerprint 115 in high resolution. One way to achieve a small packaging size is through novel optical design. For example, the imager 110 may include a Holographic Optical Element (HOE). The HOE allows the fingerprint camera 120 to be positioned close enough to the fingerprint 115 being imaged to receive, without use of large collecting optics, high resolution image features of the fingerprint 115

Although a holographic optical element allows for minimizing the size of the fingerprint imager 110 and, consequently, the fingerprint sensor 100, the HOE is generally temperature sensitive. Therefore, compensating for the temperature sensitivity of the HOE is useful for acquiring accurate, high-resolution images of the fingerprint 115. Compensating for the temperature sensitivity of the HOE can be passive or active and is discussed further beginning in reference to Fig. 2.

Continuing to refer to Fig. 1, the fingerprint camera 120 includes an interface to communicate bidirectionally with a local computer 130 via a control channel/data link 125. The fingerprint camera 120 sends image data 160 to the local computer 130, and the local computer 130 may send control data 165 or other information, including image data 125, to the fingerprint camera 120 or imager 110 via the link 125.

The local computer 130 may include a variety of processing capabilities, such as modeling, authentication, and authorization, that is applied to the image data 160. The local computer 130 may be in communication with a local database 135 via a local link 132. Image data and associated model(s) 170, collectively, are communicated between the local computer 130 and local database 135 via the local link 132. Other data, such as administrative data, may also be communicated over the local link 132 for storage in the local database 135 for later retrieval.

The local computer 130 may also communicate with a remote computer 150 via a computer network 140, such as the Internet. The image data and associated model(s) 170 are communicated via network communications links 145 among the local computer 130, computer network 140, and remote computer 150. The remote computer 150 is in communication with the remote database via a remote database link 152.

The remote computer 150 may include some or all of the processing of the local computer 130 or include other services, such as remote retrieval of image data and associated model(s) 170 from a remote database 155 or authentication of a live scan image of a fingerprint.

Fig. 2 is a hierarchical diagram of the fingerprint sensor 100. The fingerprint sensor 100, as discussed in reference to Fig. 1, includes a fingerprint imager 110 and fingerprint camera 120. Each will be discussed in turn.

The fingerprint imager 110 includes, optics 210, and, optionally, active control circuits/element(s) 225. . The optics 210 includes a light source 205, optical elements 250, which are non-HOE's such as a waveguide and lens(es), and at least one HOE 410, which includes a hologram.

The light source provides a collimated and expanded beam of light 207. The light source includes one or more beam shaping optical elements, and may include a coherent source, such as a laser diode, which works efficiently with a HOE, or a non-coherent source.

The optional active control circuit/element(s) 225 may include an angle controller 230 and actuator 235. The actuator may be a Direct Current (DC) motor, stepper motor, piezo-electric actuator, or other electro-mechanical device capable and adaptable for use in moving the light source 205 at angles fine enough for use in the fingerprint sensor 100. A wavelength controller 240 may also be employed in the imager 110, where the wavelength controller 240 may be used to change the wavelength of the light source 205 in order to compensate for temperature-induced changes in the Bragg condition of the HOE. A power controller 245 may also be employed by the imager 110 to control the output power of the light source 205 for controlling exposure levels of the fingerprint 115.

The fingerprint camera 120 includes a sensor array 215 and electronics 220. The sensor array 215 may be a Charge Coupled Device (CCD) or a Complementary Metal Oxide Semiconductor (CMOS), for example, and have a number of pixels providing a resolution fine enough for use in the fingerprint sensor 100. The electronics 220 are coupled to the sensor array 215 for receiving pixel data for processing. The electronics may include a processor, memory, and sensor data communications interface.

It should be understood that the hierarchical diagram of Fig. 2 is merely exemplary and could be configured in other ways and include additional or fewer components for implementing the principles of the present invention.

Fig. 3A is a generalized schematic diagram of the fingerprint sensor 100 and includes a subset of the components introduced in Fig. 2. The imager 110 of the fingerprint sensor 100 includes the light source 205 projecting a light beam 207 into the optics 210. An actuator 390 may be mechanically connected to the light source 205, to the optics 210 or to both, directly or indirectly, to direct the light beam 207 into the optics 210 in a controlled angular manner. Active control circuit(s) 225 provide(s) control signal(s) 389 to the actuator 390 and/or the light source 205 in accordance with the descriptions above in reference to Fig. 2. The active control circuit(s) may receive feedback from the actuator 390 or light source 205 for control or regulation purposes.

In this embodiment, a feedback signal 391 is presented to the active control circuit(s) 225 by the camera electronics 220. As in the case of typical feedback control systems, the feedback signal 391 is generated by the camera electronics 220 as a function of a difference between an actual signal level and a desired signal level corresponding to imaging performance. In the case of the fingerprint sensor 100, the feedback signal 391 may represent a deficiency in light intensity emitted by the light source 205, or may represent an angular error of the light beam 207 projecting onto the optics 210, where the angular error may be caused by temperature effects on the HOE. The camera electronics 220 may determine the feedback signal 391 based on the image data 160, subset thereof, or other signal provided by the sensor array 215. Other photosensitive areas 380 outside the active pixel field of the sensor array 215 may provide a signal 382, to the camera electronics 220, from which the feedback signal 391 is derived.

The camera electronics 220 may also provide a control signal 165 to the sensor array 215 for use during imaging of the fingerprint features image 302. Further, the camera electronics 220 also includes an interface (not shown) for communicating with the local computer 130 via the communications link 125 for transferring the image data 160.

Fig. 3B is a detailed schematic diagram of the fingerprint sensor 100. A brief description of the imager 110 and camera 120 is described in turn.

The imager 110 includes a power control circuit 245, angle control circuit 230, and wavelength control circuit 240. The power control circuit 245 provides feedback signals to the light source 205 via an interface 393. Similarly, the wavelength control circuit 240 provides feedback to the light source 205 via an interface circuit 398. The angle control circuit 230 provides a signal to the actuator 235 via an interface 396.

The optics 210 includes optical elements 250 and at least one HOE 410. The optical elements 250 and HOE 410 are arranged in a manner adapted for imaging the features of the fingerprint 115. Details of the arrangement between the optical elements 250 and HOE 410 are described in detail beginning in reference to Fig. 4.

Referring now to the details of the fingerprint camera 120, the electronics 220 include multiple electrical components, including: logic 330, microprocessor 335, microprocessor memory 355, system memory 345, interface circuit 360, and Analog-to-Digital Converter (ADC) 322, in embodiments where the sensor array 215 outputs data in the form of analog signals. The microprocessor 335 may be integrated into the logic 330 or may be a separate component communicating with the logic 330 over a bus (not shown). The logic 330 may be a Field Programmable Gate Array (FPGA) or other logic device or a processor adapted for performing the functions described herein with regard to the logic 330.

Communication between the sensor array 215 and the logic 330 occurs via a control interface 325, data bus 320, and, in certain cases, an alternate data line 385. Data is 'read out' of the sensor array 215 via the data bus 320 at a rate between 1 MHz and 60 MHz, in some applications, but may be increased or decreased based on the application and technological limits. In this embodiment, an additional photosensitive area 380 outside the active pixel field of the sensor array 215 may provide a feedback signal 382 via the line 385 to the logic 330 for use in providing the power feedback 392 to the power control circuit 245, the angle feedback 395 to the angle control circuit 230, or the wavelength feedback 397 to the wavelength control circuit 240, or any combination thereof. The logic 330 may be designed to receive signals from a subset of pixels in the sensor array 215 for use in computing

an angle feedback signal 395, wavelength feedback signal 397, or power feedback signal 393, or any combination thereof. The logic 330 or microprocessor 335 may determine the feedback signals 391 (i.e., power feedback 392, angle feedback 395, or wavelength feedback 397) through use of various techniques, such as a Least-Means-Square (LMS) technique, optimization techniques, intensity differencing technique, or other process useful for determining single- or multi-variable control.

Continuing to refer to Fig. 3B, the microprocessor 335 communicates to the microprocessor memory 355 via a microprocessor memory bus 350. The logic 330 communicates with system memory 345 via a system memory bus 340. The system memory 345 may communicate with the interface circuit 360 via a memory/interface bus 365. The interface circuit 360 communicates with the logic 330 via a logic/interface control bus 370 and logic/interface data bus 375. The interface circuit 360 communicates with the local computer 130 via a local bus 125, which includes control lines 362 and data lines 364.

In operation, the light source 205 produces an expanded, collimated optical beam 207 that is projected by the optical element 450 and HOE 410 to reflect off a cover plate 420 for imaging the features of the fingerprint 115 by the sensor array 215. The sensor array 215 outputs data representing an image of at least a portion of the fingerprint 115 to the logic 330 via the data bus 320 at a sampling rate of, for example, 40 MHz. The logic 330 directs the image data 160 to different places in various embodiments. For example, in one embodiment, the logic 330 directs the image data 160 to the system memory 345 for additional processing or directs the image data 160 to the interface circuit 360 via the logic/interface data bus 375 for direct transmission to the local computer 130. The logic 330 may also direct a portion of the image data 160 to the microprocessor 335 for determining the feedback signals 391 in an embodiment in which active feedback control is employed in the fingerprint sensor 100.

Fig. 4 is a schematic diagram of the imager 110. Referring first to the imager 110, the light source 205 produces coherent, expanded beam of light 207 at a wavelength of, for example, 655 nm. The light beam 207 enters the optical element 405 at an angle that causes the light 207 to be guided through the waveguide 405 by total internal reflection at the substrate-air interfaces. The light beam 207

encounters an interface between a Holographic Optical Element (HOE) 410 and the substrate waveguide 405, at which point, a portion of the light beam 207 is diffracted by the HOE, which includes a holographic grating, at a near normal angle to the guide surface and travels through a cover plate 415 to the finger 105. Fresnel reflection of the diffracted light at the interface of the cover plate 415 and fingerprint 115, referred to herein as a "finger contact surface" ,directs some of the diffracted light back through the HOE 410, through the substrate waveguide 405, and onto the entrance face (i.e., sensor array 215) of the camera 120. Reflection at the cover plate is suppressed at locations where objects come into optical contact with the cover plate. The remaining reflected light carries an image of these contact areas to the camera 120. The image data 160, which represents an image of the fingerprint 115, is directed across the data bus 125 to the local computer 130 in a manner as discussed above in reference to Fig.1.

One example embodiment of the fingerprint imager 110 is constructed as follows. The light source 205 is a laser diode that emits 5 mW of light at 652nm. The substrate (e.g., glass) waveguide 405 has an entrance face for the laser light 207 that is beveled to an angle of about 60 degrees from the horizontal. The dimensions of the waveguide 405 are 36 mm long, 2.5 mm thick, and 25 mm wide. The cover plate is 1 mm thick and having a square surface of 25 x 25 mm. In this example, the image of the fingerprint 115 is captured by a CMOS electronic imager having a 1024 by 1280 array of 6 μm square pixels and 256 gray levels. The size of the resulting image is 6.1 mm by 7.7 mm, while its resolution is 167 pixel per mm or 4200 pixels per inch.

In operation, when the finger 105 is pressed onto the finger contact surface 420, the ridges of the fingerprint 115 make optical contact and suppress reflection. Since pores are depressions along the ridges, there is reflection from the cover plate at pore locations. The resulting image of the fingerprint 115 that is presented to the camera 120 includes light colored areas for the valleys and dark ridges with light pores aligned along the ridges. An undistorted, high-resolution image of the fingerprint 115 can be captured by the camera if the light beam 207 that is diffracted by the HOE 410 is collimated and has a uniform wavefront.

Fig. 5 is a schematic diagram of a subset of the camera electronics 220. This schematic diagram provides a layout of the sensor array 215 and the FPGA 330. The size of these components 215, 330 results in a particular layout in which the finger 105 is positioned on top of the imager 110 in a manner such that the fingerprint image 500 acquired by the sensor array 215 may be mis-oriented in a way that inverts the left-right orientation of the image, for example, or rotates the image to a position clockwise from the desired viewing position, for example. The image is preferably, and in some cases must be, acquired and displayed in the same orientation as observed when inked and rolled on a white card, to preserve the traditional orientation used to store and compare pre-existing law enforcement image databases. Therefore, the FPGA 330 may be programmed to change the image orientation through predefined data manipulation. For example, the system memory 345 may be designed to store two or more times the amount of image data 160 so as to allow the FPGA 330 to rewrite the image data within the memory in a manner for reading-out the data to the local computer 130, which allows the fingerprint image 500 to be displayed to a viewer in a standard "tip up" orientation. In the case of a large system memory, the size of the system memory 345 also allows for storage of multiple data size fingerprint images 500 for buffering or averaging purposes. It should be understood that the system memory 345 may be larger or smaller than just described depending on the particular application.

Fig. 6A is a hierarchical diagram of the local computer 130. The local computer 130 includes a sensor data/control interface 605, software 610, display 630, local storage 635, and network interface 640. The software 610 includes processing software 615, a Graphical User Interface (GUI) 620, the local database 135, and sensor control software 625. The local computer 130 can be a standard computer that is customized to operate with the fingerprint sensor 100 or can be a custom-designed computer that includes specific, optimized hardware, such as a specific sensor/data control interface 605 to optimize performance with the fingerprint sensor 100.

Fig. 6B is a block diagram of example processing software 615 that may be loaded and executed by the local computer 130. The processing software 615 may include acquisition software 645 (Fig. 14), enrollment software 650 (Figs. 13-15),

analysis software 655 (Figs. 16-20), administrative software 660 (e.g., database administration), and additional information processing software 665 (e.g., security features, header information, and watermarking). Details of the processing software 615 are described in detail below in reference to the indicated associated figures.

Fig. 7 is a system level flow diagram of a process 700 for (i) imaging the fingerprint 115 with the fingerprint sensor 100 through (ii) processing image data 160 representing an image of at least a portion of the fingerprint. The process 700 begins with the fingerprint sensor 100 capturing fingerprint image data (step 705). The image data 160 is presented to the fingerprint camera processor 335 or local computer 130 for preprocessing (step 710). Preprocessing can help speed system performance significantly, while maintaining more cost effective imager to computer interfaces that might otherwise be bandwidth limited. Preprocessing 710 may include changing the image orientation, calibrating the image, scaling the image, flattening the field across the pixels of the sensor array 215, correcting for defective pixels of the sensor array 215, decimating the captured image data 160, applying encryption to the image data, applying a watermark to the image data, adding header information to the image data, or compressing the data, optionally through a lossless compression technique. Other forms of preprocessing may also be applied for transmission and/or storage with the image data 160.

The image data and, optionally, the additional data (collectively 725) is provided to the fingerprint camera processor 335, local computer 130, or remote computer 150 for processing the image data 160 (step 715). Examples of processing the image data 160 include: modeling the features of the fingerprint, enrolling the fingerprint, authenticating the individual associated with the data representing at least a portion of the fingerprint, and identifying the individual. The process 700 ends in step 720.

Fig. 8 is a flow diagram of a process 800 for modeling the image as a function of the fingerprint features. The image data 160 is processed by a gradient edge detector 805. The gradient edge detector provides the image data and fingerprint features (collectively 815) to a modeler 810. The modeler generates a model of the fingerprint as a function of the fingerprint features. The modeler 810 outputs image data and model(s) (collectively 170) to a local database 135 or other

processor, such as the remote computer 150 for additional processing or storage in the remote database 155, for example.

Figs. 9-12 include images of fingerprints 115 that are (i) displayed to a user, (ii) modeled, (iii) processed (e.g., authenticated, identified, etc.), or (iv) stored for later retrieval. Figs. 13-20 include example processes that improve the analysis of both high-resolution fingerprints that contain resolved pores and lower resolution fingerprints without resolved pores. The processes of Figs. 13-20 do so by using identifying information in a fingerprint, which can include ridge shapes or profiles in addition to the traditional ridge contours, and the position, shape and prominence of pores. Before describing the processing, a brief description of the fingerprint images and overlays indicating fingerprint features determined by the processing is described.

Fig. 9 is an example of a fingerprint image 900, represented by the image data 160, that was acquired with the fingerprint sensor 100. Light colored (e.g., gray) valleys (V) 905 and dark ridges (R) 910 are observable. Examples of pores (P) 915, ridges 910, ridge details (RD) 920, and minutiae (M) 925 are all indicated in the figure. Some or all of these types of features can be used by the processes of Figs. 13-20 to compare and match fingerprint images 900. The fingerprint image 900 contains fewer than ten minutiae 925 and almost ten times as many pores 915 as minutiae 925.

Fig. 10 is an example of the image data 160 including indications of features obtained at the "outline" resolution level. Thick lines 1005 trace identified boundaries between ridges 905 and valleys 910 and outline some of the pores 915. Features that are outlined in thick lines 1005 are considered real and are used for subsequent fingerprint matching steps. Noise is traced in thin lines 1010 and is not used for matching. A trained model of a single fingerprint includes one or more of these feature sets from various regions of the complete fingerprint image data 160.

Fig. 11 is an example of the fingerprint image data 160 with a smaller central region 1105 containing highlighted features that were identified using gradient edge detection procedures, discussed below beginning at Fig. 13. The features were obtained at the "details" level of resolution. Similar to Fig. 10, thick lines 1110 indicate "real" (i.e., non-noise) features and thin lines 1115 indicate noise.

The local computer 130 may display the image data 160 in the form of the fingerprint image 900 in the GUI 620. Through use of standard or custom GUI techniques, the user can, for example, (i) select specific features that must be present for a match, (ii) move the modeled region 1105 in any direction to model different area, (iii) enlarge or reduce the size of the modeled region, or (iv) select or deselect features within the region to reduce noise from being part of the model, or to include specific features within the region.

Fig. 12 is an expanded view of the model region 1105 from the fingerprint shown in Fig. 11 that includes indications of features or noise operated on by the user via the GUI 620. In the fingerprint image 900, the thick gray lines 1110 are real, and the black lines 1115 are noise. However, the user may want to change the results produced by the automated processing. For example, the user may use a Graphical User Interface (GUI) to deselect certain features 1205 he or she may consider noise even though the automated processing considered the features 1205 real fingerprint features. The manual selection process may also work in reverse, where features the automated processing considers noise may be reselected by the user to be included as real fingerprint features 1210 through use of the GUI 620.

There are thousands of features included in the enrolled model information set. A later comparison to these features that finds, for example, 80% of the total enrolled features means that 4000 separate features were found that match an original enrolled image of 5000 total features in an area as small as 5x5mm, for example.

In addition, the user may define specific features 1215, or a percentage of specific features as being required, in addition to a percentage of all features, as qualification criteria for a match. The more features 1215 that are required for a match reduces the likelihood of false detections but increases the likelihood of missed detections. Therefore, a threshold number of required features 1215, such as 80%, may be specified to account for noise, distortions, lighting or other imaging-related effects.

Multiple biometrics (e.g., multiple fingerprints of an individual; fingerprint(s) and palm prints; fingerprint(s) and iris scan; and so forth) may be acquired and modeled. The multiple biometrics may be combined in various

manners, such as root-mean-square or weighted sum, to for a "combined metric." The combined metric may be used for later comparing of the acquired multiple biometrics with future acquired images (e.g., live scans). Combining multiple biometrics may improve system reliability.

The image data and model 170, collectively, may be transmitted as a paired set from the local computer 130 to the local database 135 or remote computer 150 as discussed above in reference to Fig. 1. In applications where the smallest possible model is required, on a smart-card or drivers license, for example, only the model, without the accompanying image may be used. The outline features, details features, required features 1215, and fine details (e.g., pores) features may be stored as part of the model and used during later processing.

Referring now to processing aspects of the present invention, two major steps are described: fingerprint enrollment (Figs. 13-15) and fingerprint matching (Figs. 16-19). During enrollment, a high-resolution digital fingerprint (e.g., image data 160 representing the fingerprint image 900) is acquired, and one or more sets of features to be used for subsequent fingerprint matching are identified. Fingerprint matching compares these sets of features (e.g., ridge deviation details, such as the required features 1215, pores, and minutiae) to the unknown fingerprints and decides if the two fingerprints are from the same individual. The source for these two fingerprints can be a database of high-resolution fingerprints, a live scan image, a legacy database of lower resolution fingerprints, latent fingerprints (i.e., fingerprints "lifted" at a crime scene), or combinations of these sources. Although the invention makes use of the extensive data available with higher resolution images, the techniques also work with lower resolution images.

The processes of Figs. 13-20 describe an automatic fingerprint recognition method that identifies fingerprint features by using gradient edge detection techniques. In one embodiment, the features are acquired in gray-scale. In another embodiment, color may be part of the acquired image. The techniques identify and trace edges of structural features to outline ridges and pores. At sufficiently high resolution, the ridge outlines contain thousands of unique structural features (i.e., level three features) that can be used in fingerprint matching. This capability improves matching reliability over systems that reduce ridge patterns (by

binarization and thinning) to a few minutiae types Because of the richness of features in fingerprints at high resolution, the method and apparatus according to the principles of the present invention produces reliable, high speed matching of small prints to a much higher degree of accuracy than with standard minutiae-only based systems.

The processes of Figs. 13-20 analyze an unaltered gray-scale image of the fingerprint 115 to reduce both computing time and false accept rates. In a preferred embodiment, edge detection software is combined with high resolution image acquisition technology that is capable of resolving pores and ridge profiles.

Fig. 13 is a flow diagram of an example process 1300 for enrolling a fingerprint 115. The fingerprint 115 is first acquired (step 1305). An example process for acquiring an image is provided in Fig. 14.

Fig. 14 illustrates a flow diagram of an example process 1400 for acquiring an image of the fingerprint 115, described in reference to Fig. 4. A direct light beam 207 is transmitted through a substrate waveguide 405 (step 1405). The finger 105 is pressed onto a contact area of a coverplate (step 1410). The exposure time of the fingerprint camera 120 is adjusted (step 1415) either manually or automatically. The fingerprint image 302 (Fig. 3A) is captured (step 1420), and the process 1400 returns (step 1425) to the process 1300 of Fig. 13 for further processing.

Referring again to Fig. 13, after acquisition, the image data 160 is transferred (step 1310) to the local or remote networked computers 130, 150, respectively, by one of a number of possible connecting protocols, such as, but not limited to, IEEE 1394 (Firewire), USB, Serial ATA, fiber-optic cable, any applicable wireless communications protocols, such as BlueTooth or 802.11g, or Ethernet. The image data 160 is then converted (step 1315) to a desired file format, and header information, and optionally a watermark, may be added to the image data 160. The header may contain information regarding the fingerprint 115 and how, when, and where it was acquired, the manufacturer, model and serial number of the acquisition device, the unique ID and name of the computer as well as the name of the operator logged on to the operating system, and pointers to related information, such as personal information about the individual, including, but not limited to, a photograph, voice recording (sometimes referred to as a "voice print"), signature, or

other identifying information. A watermark can be added to protect the image and data header from subsequent unauthorized alteration. One example of a procedure to add a watermark to fingerprint images is described by Yeung and Pankanti, "Verification watermarks on fingerprint recognition and retrieval" Journal of Electronic Imaging, 9(4), 468-476(2000). Commercial watermarking procedures can also be used.

Continuing to refer to Fig. 13, after the fingerprint is acquired (step 1305), specific and unique features of the fingerprint are identified, extracted and stored as a "trained model" (step 1320), according to a process described below in reference to Fig. 15. The model may be used for subsequent fingerprint verification (one-to-one matching) by comparing the feature sets of the model to the corresponding features of a subject, or "present," image. Features from the entire image are usually extracted and stored for fingerprints that are to be used for fingerprint identification (one-to-many matching). An example process of constructing a model is described in reference to Fig. 15.

Fig. 15 is a flow diagram of an example process 1500 for creating a model of a fingerprint that can be used for subsequent analysis and matching. At least two models are constructed (step 1505) from high resolution images: a low resolution "outline" model that comprises ridge contours, and a high resolution "details" model that comprises ridge contours, ridge shapes, and pores. Details regarding ridge shapes and pores are generally not considered in the outline model; compare Fig. 10 for an example of the features that are typically identified at the outline level to Figs. 11 and 12 for features found at the details level. A further refinement adds a third, more highly detailed model specifically designed to more closely identify pore feature information, such as area, and centroid location. Edge detection levels may be changed for each of the three models in order to identify specific details, such as pores within ridges, with higher accuracy.

Since the outline model contains less information, computation time is reduced by first comparing images at the outline level for a candidate match before attempting to match candidate images at the details level. Both outline and details models may be constructed using the same procedure of gradient edge detection (e.g., gray-scale gradient edge detection) (step 1515). In one embodiment, the

outline model is determined from a subset of pixels of the original image; each pixel of the subset is an average value over a predetermined number of neighboring pixels from the original image. The first step during fingerprint matching is to compare outline models. Matches may be discovered at the outline level and then compared at the details level. Detailed matches may then be supplemented by required details, and then further to be compared at the fine details pore level.

Images acquired by the fingerprint imager 110 of Fig. 4 are 6.1 mm by 7.7 mm, in one embodiment. This relatively large fingerprint is usually divided into one or more smaller regions that are individually used to construct individual model(s) (step 1510). These model regions can either be chosen manually to capture particularly interesting features found in a specific region, or they can be chosen automatically using adjustable software settings that define the number of regions, region size, and region locations. Their size is preferably chosen to be large enough to include numerous characteristic features and small enough to reduce problems associated with plastic deformation of the skin and to minimize computation time by using a smaller relative model size. The features identified in a sub-region of the complete fingerprint are referred to as a "feature set." A trained model comprises a collection of all of the feature sets for a particular fingerprint, or several trained models may each contain feature sets for a portion of the particular print

Features, for each resolution level and in each region of the fingerprint chosen to be part of the trained model, are identified using gray-level gradient edge detection procedures (step 1515) and extracted. The gradient is first estimated for each of the pixels of the model using one of a relatively large number of procedures that have been developed for this process (see for example D. A. Forsyth, and J. Ponce, "Computer Vision A Modern Approach", Prentice Hall, New Jersey, 2003, chapter 8,).

A particularly useful procedure that is often used to estimate gradients is to apply a Gaussian noise filter to the image and then to perform the gradient calculation using a "finite differences" algorithm. After calculation of the gradients, an image point with a locally maximal gradient in the direction of the gradient is identified and marked as an edge point. The next step is to identify neighboring edge points. This is usually accomplished by finding the nearest pixels to the

original edge point that lie in a direction that is approximately perpendicular to the gradient direction that passes through the first edge point. The gradient values for these new pixels are determined, and the pixel with a gradient that is (i) maximal along its gradient direction and (ii) has a value that exceeds a threshold is assigned to be the next edge point. This procedure is continued either until the edge is terminated or the edge closes with itself to form a continuous curve. Edge termination occurs at the previously determined edge point if the gradient of a candidate edge point is less than the threshold. In the next step a previously unvisited edge point is identified and its edge is traced according to the steps outlined above. This whole process is repeated until all of the potential edge points have been considered. Automatic software procedures are then used to distinguish fingerprint features from noise. Real edges, for example, must define features that have a minimum width. In addition, lines that do not enclose pores must extend for a minimum distance in order to be considered as legitimate feature edges. Further, pores only occur in ridges and not in valleys. Additional rules may be applied by adjusting software settings. Optional steps allow the models to be manually edited by adding or deleting features (step 1520) and allow users to indicate certain features of the model that must be present for a successful match (step 1525). All editing is performed on the features and not on the original image, which is deliberately protected from any alteration. Examples of features that are identified by this procedure were introduced above in reference to Figs. 10-12. A number of commercial software applications can be used for edge detection, or custom software applications may be designed for executing the processing described herein. The process 1500 returns (step 1530) to the enrollment process 1300 of Fig. 13.

Referring again to Fig. 13, after feature extraction to produce the trained model, the original fingerprint image and model data 160 is optionally indexed, compressed and encrypted (step 1325), and stored with the model (step 1330). One compression procedure is the Federal Bureau of Investigation (FBI) standard for 500 dpi fingerprints, referred to as Wavelet/Scalar Quantization (WSQ). This is a lossy scheme with a compression ratio of 12.9. According to the FBI standard, the compressed image needs to form a record of the original print that can be used for

manual matching and for some automatic matching procedures. Alternatively, a lossless compression technique may be employed for storing the image. The trained model used for matching, on the other hand, requires much less storage space and may be stored with or without compression.

Fingerprint matching is used either to verify the identity of an individual (referred to as 1:1 matching) or to identify the source of an unknown fingerprint (referred to as 1:n search). Both procedures compare a known fingerprint from a database either to a live scan fingerprint for verification or to an unknown fingerprint for identification. This fundamental step of fingerprint matching is the same for both verification and identification.

Fingerprint verification is a particularly important type of fingerprint matching. Fingerprint verification compares a live scan image to an enrolled image in order to authenticate the identity of the individual presenting the live scan fingerprint. Flow diagrams for fingerprint verification are shown in Figs. 16 ,17, 18 and 19.

A user first presents identification (step 1605), such as a passport, license, smartcard or other ID, name or password any of which may be used to provide or to look up his/her previously enrolled fingerprint model(s). Note that the models may be looked-up or stored on the ID, depending upon the application. Then, a live scan, high-resolution fingerprint of the user is acquired in real time (step 1620), and "outline," "details," and "pores" features for the complete fingerprint are extracted (step 1625), as illustrated in reference to Figs. 9-12.

Fig. 16 is a flow diagram of the initial process 1600 for fingerprint verification at an "outline" resolution level. An outline feature set from the trained model (steps 1610, 1615) of the user is compared to the corresponding features from the live scan image (step 1630) according to a process described below in reference to Fig. 18. This comparison is repeated until either a match is found or all of the feature sets of the model have been compared to the live scan outline features (steps 1635, 1640, 1645). If no match is found, the process 1600 ends (step 1655), and further processing at the details level does not occur for that particular model. If a match candidate is found at the outline level (step 1635), the matching procedure is repeated at the details level (process 1650) according to Figure 17A.

Fig. 17A is a flow diagram of the process 1650 for fingerprint verification at the "details" resolution level. The process 1650 selects a details feature set from the trained model (step 1705). The process 1650 compares the details features from the image and model (step 1710) according to the process of Fig. 18, discussed below. This comparison is repeated until either a match is found or all of the feature sets of the model have been compared to the live scan details features (steps 1715, 1720, 1725). If no match is found, the process 1650 ends (step 1735), and further processing at the required features level does not occur for that particular model. If a match candidate is found at the details level (step 1715), and no "required" or fine details "pores" features are specified (i.e., details threshold is met), then a positive match is declared. If a match candidate is found at the details level (step 1715) and "required" and/or "pores" are specified in the matching requirements, the matching procedure is repeated for required features (process 1730) according to Fig. 17B.

Fig. 17B is a flow diagram of the process 1730 for fingerprint verification of [the optional] required features. The process 1730 selects required features from a feature set from a trained model (step 1732). The process 1730 compares the required features from the feature set of the model to features identified in the live scan image using the same resolution that was used to obtain the required features of the model (step 1734), according to the process of Fig. 18, discussed below. The comparison is repeated until either a match is found or all of the feature sets of the model at the required features level have been compared to the live scan image (steps 1736, 1738, 1740). If no match is found, the process 1730 ends (step 1745), and further processing for pore matching does not occur for that particular model. If the required features match (step 1736), the matching procedure is repeated for pores at the "fine details" level (if any, process 1750) according to Fig. 17C.

Fig. 17C is a flow diagram of the process 1750 for fingerprint verification of the optional pores at the "fine details" resolution. The process 1750 selects pores from a feature set from a trained model at the fine details resolution (step 1752). The process 1750 compares pores from the feature set of the model to pores identified in the live scan image (step 1754) according to the process of Fig. 18, discussed below. The comparison is repeated until either a match is found or all of the feature sets of

the model at the fine details level have been tested. If the pore features threshold is met, a positive match is declared (step 1770).

Fig. 18 is a flow diagram outlining the process used to determine if a match exists between a trained model and a present image, such as a live scan fingerprint image, which is used now as an example. Fingerprint features are correlated at either the outline, details, or fine details resolutions (steps 1630, 1710, 1734, 1754). A model feature set is overlain on a feature set of the entire live scan image (step 1805). Since the model feature set is generally smaller, it will overlap only a portion of the live scan feature set. A correlation is then calculated between the model feature set and the portion of the live scan image that it overlays (step 1810). There are a number of procedures that are commonly used to determine correlation between images (for example, Maltoni, Maio, Jain, and Prabhakar, "Handbook of Fingerprint Recognition", Springer, 2003, chapter 4). A particularly useful procedure considers the similarity of two images to be indicated by their "cross correlation" (for example, Maltoni, Maio, Jain, and Prabhakar, "Handbook of Fingerprint Recognition", Springer, 2003, chapter 4). Using this procedure, the cross correlation between the live scan image and the model feature set is calculated as the feature set expands, contracts, and rotates, over predetermined limits, with respect to the live scan image that it overlays. The feature set is then translated to a new section of the live scan image (step 1825), and the cross correlation calculation is repeated. This process is followed for all the feature sets of the model (step 1820). A match is achieved (step 1830) if a cross correlation exceeds a threshold (step 1815), and if a predetermined percent of features match with the live scan image features (step 1830). Otherwise, there is no match (step 1840).

Fig. 19 is an "adaptive conformity" process 1900 optionally executed in determining the correlation (step 1810). The adaptive conformity process 1900 is used to improve performance of the correlation process of Fig. 18. Adaptive conformity allows for matching of fingerprint features in cases where linear or non-linear shifting of the fingerprint features occurs either in the original fingerprint from which an outline, and/or details, and/or fine details level model(s) is derived, or in imaging a live scan fingerprint image. Such linear or non-linear shifting is caused by elasticity of the skin in combination with pressing the finger 105 into the imaging

surface (e.g., lens 415) in various ways, such as through applying pressure in latitudinal, longitudinal, or rotational directions or in an excessively hard or light manner. In the latitudinal, longitudinal, or rotational cases, part of the fingerprint may be imaged normally, and compression, extension, or rotation may occur in another part of the fingerprint. In the excessively hard or light pressure cases, part or all of the fingerprints may include thicker or thinner ridge 905 sizes, respectively. The adaptive conformity process 1900 allows the shape of the model to adaptively conform to account for non-uniformity of fingerprinting but in a manner that does not alter or change the features in any way, thereby maintaining the integrity to the identification and verification processes according to the principles of the present invention. Similar shapes, details, and pores that are shifted slightly due to distortion are recognized as the same shapes, but in a slightly different relative position than they were on a previous acquisition. The principles of the present invention allow for highly accurate recognition of level three details even if distortion from previous enrollment has taken place, which is normal to some degree in any set of fingerprint images. In addition, better accuracy to match is obtained with slight changes due to wear of ridges, scarring, dehydration, and pressure.

Referring specifically to Fig. 19, the adaptive conformity process 1900 may be executed for authentication or identification (i.e., verification) processes, and with any image source including but not limited to latent images. After starting (step 1905), the process 1900 returns to the fingerprint feature correlation process 1800 of Fig. 18 if adaptive conformity is not selected to be applied by the user (step 1920). In one embodiment, the user may select adaptive conformity to be selected through toggling a Graphical User Interface (GUI) control. If adaptive conformity is selected, the process 1900 identifies a candidate match start location (step 1915), such as the core (i.e., center of fingerprint "swirls"), and uses the start location as a "base" from which to apply the adaptive conformity linear or non-linear processing.

After identifying the start location, the process 1900 locates the pixels where edge topology (i.e., outline level) features of the model and the image deviate. Using the deviation point as a "base point of adaptive conformity," the process 1900 attempts to conform potentially corresponding model pixels beyond the base point laterally, longitudinally, or radially (step 1930) with the fingerprint features of the

live scan fingerprint image. Conforming the potentially corresponding model pixels means to shift the model pixels in a predetermined direction without changing the shape of the outline or details features of the model. If the chosen predetermined direction is correct, the shifting of the edge topology continues by shifting pixels in the same direction from the base deviation while the shape of the edge topology continues to match (steps 1935, 1940, and 1945) or until the edge topology being examined is complete. If the chosen predetermined direction is incorrect, other directions may be tried. Distance ranges for allowing pixels to move in attempting to adaptively conform can be specified by the user but are limited in range to that typical of these types of distortions.

Additional testing at the outline level continues (step 1950) until the outline feature sets of the model are compared with the outline features of the live scan image (steps 1950 and 1925-1945). Following comparison of the outline features, the process 1900 repeats the adaptive conformity process at the details level (step 1955). The process 1900 returns to the process of Fig. 18 at step 1810 following completion (step 1960) at the details level. In an alternative embodiment, if the matching at the outlines level does not achieve a predetermined threshold, the processing at the details level (step 1955) is skipped with an appropriate message being passed to the process of Fig. 8.

Fingerprints from an unknown individual can sometimes be identified by comparing the unknown print to a database of known prints; this is referred to as 1:n fingerprint identification. A particularly advantageous procedure is to compare fingerprints in a database of high resolution fingerprints that were acquired and processed according to the processes of Figs. 13-15 with a high resolution unknown fingerprint. In this case, each fingerprint in the database has an associated "outlines" and "details" and optionally, a "required" and "pores" feature set that encompasses the entire fingerprint image. A trained model is formed from the unknown fingerprint and compared to the feature sets of the database. To save computation time, the comparison is first made at the "outline" resolution level. The subset of candidate fingerprints that match at the outline resolution level is subsequently compared at the "details," and optionally at "required" or "pore" resolution(s).

It is also possible to compare a relatively low resolution unknown print to prints in either a high or a low resolution database. In these cases, the feature set for the unknown fingerprint includes only ridge patterns and does not contain information on ridge profiles, ridge shapes, or pores. The processes described herein exhibit enhanced reliability over minutiae-based systems even in this case since all of the information of the fingerprint is used for comparison and not just a few minutiae points.

In most examples of fingerprint identification, appropriate linear scaling might be necessary since the unknown fingerprint may have been acquired at a different magnification from the fingerprints in the comparison database. The GUI 620 allows a user to graphically mark a line having start and end points of a scale (e.g., ruler) imaged with the original fingerprint and assign a length value to the length of the line. In this way, proper scaling can be applied for comparison against a live scan image, for example.

Similarly, appropriate angular rotation might be necessary since the unknown fingerprint may have been acquired at a different angle than the fingerprints in the comparison database. The GUI allows a user to indicate a range of rotation (e.g., + or – 30 degrees) to check the live scan image against the outline level of the comparison model. In this way, proper orientation can be obtained for the comparison, and subsequent details, required, and pore features can then be applied at the same rotation, for example. Checking a larger degree of scale and/or rotation takes more computing time, so faster compare times are achieved if some degree of normalization is first preprocessed in order to limit the degree of scaling and/or rotation that is required for reliable operation of the system.

In addition to the processing described above, the principles of the present invention support preprocessing that can improve performance of the processing (i.e., modeling and comparisons). Example forms of preprocessing include: image orientation and rotation, sub-sampling, decimating, binning, flattening the field, accounting for defective pixels in the sensor array 215, encrypting the image data 160, applying a watermark, and attaching sensor information.

Figs. 20A and 20B are illustrations of one form of preprocessing, namely accounting for defective pixels. Referring first to Fig. 20A, a grid 2000 illustrates an

example of a small region of pixels in the sensor array 215. The processing region of interest 2005 starts at a first position. In this embodiment, the processing region of interest is composed of an array of 3x3 pixels. Alternative embodiments may utilize alternative array sizes (5x5, 9x9, etc) or alternative array shapes (rectangular) ultimately determined by the desired resolution of the fingerprint sensor and the desired image quality. In the present example, there are multiple bad pixels in the sensor array 215, each represented by a zero '0'. Among the pixels, there are known good pixels represented by a one '1'. In the center of the processing region of interest 2005 is a pixel of interest, represented by a plus sign '+'. In this example, the pixel of interest, if a defective pixel, may be corrected by obtaining an average of at least two neighboring pixels within the processing region of interest 2005. The average value of the neighboring pixels can then be assigned to the defective pixel of interest. Once a pixel of interest has been corrected (if necessary), the processing region of interest 2005 is moved by one pixel spacing in order to address the next pixel in the array. The direction of movement of the processing region of interest 2005 may be in the most convenient direction for processing efficiency or dictated by the architecture of the particular system.

Fig. 20B is an example of the shifting of the processing region of interest 2005 to a neighboring pixel on the pixel array 2000. Noting that the pixel of interest previously corrected in Fig. 20A is now denoted as a 'C' pixel in Fig. 20B, the processing region of interest corrects the next pixel of interest (also donoted by a + in Fig. 20B) by averaging two known good pixels from within the processing region of interest 2005. In alternative embodiments, previously corrected pixels (denoted as 'C' in Fig. 20B) may be used as a good pixel for the purposes of correcting the new, defective pixel of interest.

Although this embodiment averages the intensities of two known good pixels within each processing region of interest to correct for a defective pixel, alternative embodiments may average the intensities of more than two known good pixels. In yet another embodiment, a defective pixel of interest may be replaced by intensity data from one known good pixel from within the processing region of interest 2005, wherein the processing region of interest 2005 may be of an array size larger than

3x3 or the processing region of interest array size may not be a square two-dimensional array.

The other examples of preprocessing are now described without reference to associated figures.

Subsampling is a form of reducing the amount of data sampled by the fingerprint camera 120. Instead of reading data from every pixel of the sensor array 215, the camera 120 reads a subset of the pixels in a predefined manner, which is preferably selectable by the user. Decimating is another form of reducing the data, but reduces the amount of data after the data has been read from all or substantially all the pixels of the sensor array 215. Binning is a technique for reducing the amount of data representing the fingerprint by averaging data of multiple pixels into a single value; for example, four pixels may be averaged as a single average value to reduce the data by a factor of four.

Flattening the field is also referred to as correcting for uneven illumination of the fingerprint image. Uneven illumination of the image may be caused by many sources, such as the light source 205, the propagation path of the light beam 207, the optics 210 (including the optical elements 250 or HOE 255), or the gain or offset of the pixels of the sensor array 215. Testing for uneven imaging of the fingerprint may be done during a calibration phase prior to acquiring an image of a fingerprint, where a reflection off the fingerprint imaging surface is used as the source and calibration data is determined and stored in the microprocessor memory 355 (Fig. 3B), for example. The calibration data is applied during live scanning of a fingerprint 115.

In addition to reducing data or correcting for imaging or equipment issues, the preprocessing may also be used to apply additional information to the image data 160. For example, the image data 160 may be encrypted using various forms of well-known encrypting techniques. A header may be applied to add a variety of equipment-related information or other information that may be useful to determine the source of the equipment or understand the environmental conditions that were present when the fingerprint was imaged for use at a later time, such as during authentication or authorization. Example information may be the manufacturer, model and serial number of the instrument supplying the image data 160

representing the portion of the fingerprint, date of fingerprinting, time of fingerprinting, calibration data associated with the instrument used to acquire the image, the name of the operator logged onto the operating system, the unique ID of the computer that was used to acquire the image, and temperature at the time the image was acquired.

A watermark may also be associated with the data. An example technique for applying a watermark is to use extra data bits associated with each pixel to represent a portion of the watermark. For example, if each data pixel only represents two hundred fifty-six (2^8) levels of gray-scale, two bits of a ten-bit word may be used to represent a portion of a watermark. The watermark may be information that would otherwise be part of a header or may be information that is used to determine whether any tampering has occurred with the fingerprint image.

The processing and preprocessing discussed herein may be implemented in hardware, firmware, or software. In the case of software, the software may be stored locally with a processor adapted to execute the software or stored remotely from the processor and downloaded via a wired or wireless network. The software may be stored in RAM, ROM, optical disk, magnetic disk, or other form of computer readable media. A processor used to execute the software may be a general purpose processor or custom designed processor. The executing processor may use supporting circuitry to load and execute the software.

While this invention has been particularly shown and described with references to preferred embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the scope of the invention encompassed by the appended claims.

For example, in Fig. 1, the fingerprint sensor 100 and local computer 130 are distinct devices with a majority of the processing occurring in the local computer 130. In an alternative embodiment, the fingerprint sensor 100 includes an embedded processor capable of performing preprocessing as well as some of the processing functions of the local computer 130, as discussed in general in reference to Figs. 6A and 6B and in detail in reference to Figs. 13-20. Also, the processing may be done in the remote computer 150.

The control channel/data link 125 or other links 132, 152, 145 may be wired or wireless links, such as through Radio Frequency (RF) or infrared communications. In another embodiment, the fingerprint sensor 100 may have IEEE 802.11, cellular communications (e.g., Code Division Multiple Access (CDMA)), or other wireless capability to interface directly to a wireless node (e.g., base station, not shown) in the computer network 140.

The local and remote databases 135, 155 may be any form of database and located with or distinct from the associated computers or distributed about the computer network 100. There may also be security provisions associated with the databases 135, 155 so as to prevent tampering with the fingerprint image data and models 170 stored therein.

In Figs. 3A and 3B, real-time automatic feedback control of power, angle, or wavelength is illustrated. In alternative embodiments, mechanisms to allow for manual adjustments may be provided. Also, periodic, random, or calibration period adjustments instead of real-time feedback control may be employed to reduce power consumption. The power source for the fingerprint sensor 100 is described above as being the local computer 130 via Firewire or other interface; however, it should be understood that the power source may be a battery (not shown) or AC-to-DC power converter with sufficient filtering circuitry to achieve the high-resolution images. Also, the sensor array 215 may be a CCD array or any other array adapted for use in the fingerprint imaging application for achieving resolution sufficient to detect the fingerprint features described herein.

In Figs. 6A and 6B, the software 610 may be any language adapted to be executed in the fingerprint sensor 100, local computer 130, or remote computer 150. For example, the software may be assembly language, 'C', object-oriented C++, Java, or combinations thereof. It should be understood that the processing and display of live scan images should be displayed in near-real-time, preferably with outline or details models displayed thereon.

Fig. 7 may omit the preprocessing 710 and processing 715 of the image data 160. Instead, the image data 160 may be stored in one of the databases 135, 155, for example, and processed according to the preprocessing 710 or processing 715 techniques as described herein in a post-processing, non-real-time manner.

Additionally, in another embodiment, after images are captured by the fingerprint sensor 100 and indexed and stored, certain software-based enhancements may be performed, if needed, at the option of a system configuration administrator or for other beneficial reasons. Certain enhancements that do not alter the original image or its unique characteristics can be performed to enhance image analysis, such as mean low-pass filtering or automatic level adjustment to improve contrast or other methods that include, but are not limited to, gray-scale gradient edge detection techniques for pattern recognition and subsequent matching techniques, or combinations thereof.

A number of commercial software applications can be used for edge detection, including Aphelion from Amerinex Applied Imaging, Hexsight software from Adept, Vision Blox distributed in the U.S.A. by Image Labs, and Halion from The Imaging Source.

Fig. 8 illustrates a gradient edge detector 805 and modeler 810 as distinct operational units. In alternative embodiments, these two operational units 805, 810 may be combined into an integrated operational unit or distributed and executed about multiple processors. Further, the image data and model(s) 170 may be stored in the local database 135, as shown, or stored in different databases for size, security, or administrative reasons.

Figs. 9-12 are fingerprint images 900 embodied in high-resolution image data 160 representing the fingerprint 115. Because the processing described herein is robust, the image data 160 may be lower resolution than illustrated and still achieve the desired matching results. In addition, the gradient edge detection processes described herein can accomplish the modeling and comparing processes at poor contrast levels without significant degradation to the results. However, the user may choose to lower a matching threshold at either outline or details levels to account for poor contrast levels in the original fingerprint image.

Figs. 13-20 are illustrative flow diagrams. The flow diagrams may be varied in any manner that accomplishes the processing and storage tasks suitable for achieving the acquisition, modeling, and verification aspects according to the principles of the present invention.

CLAIMS

What is claimed is:

1. A method for processing an image of a biometric comprising:

applying a gradient edge detection process to detect features in a biometric based on data representing an image of at least a portion of the biometric; and

modeling the image as a function of the features.

2. The method according to claim 1 wherein modeling the image includes constructing the model for at least two resolutions.

3. The method according to claim 2 wherein the resolutions include an outline model at a low resolution and a details model at a high resolution.

4. The method according to claim 3 wherein the biometric is an area of skin with a friction ridge pattern, the outline model includes edge topology of ridge features, and the details model includes edge topology and specifics of ridge deviations and locations and sizes of pores.

5. The method according to claim 2 wherein the resolutions include an outline model at a low resolution, a details model at a high resolution, and a fine details model used to locate and define particular biometric features more accurately than at the low or high resolutions.

6. The method according to claim 2 wherein the biometric is an area of skin with a friction ridge pattern and constructing the model includes identifying, outlining, and extracting ridge deviation detail and pore features.

7. The method according to claim 6 wherein the ridge deviation detail includes ridge contours including scars; and the pore features include position, shape, and sizes of pores.

8. The method according to claim 2 wherein the biometric includes at least one of the following: ear shape and structure, facial or hand thermograms, iris or retina structure, handwriting, fingerprints, palm prints, foot prints, toe prints.

9. The method according to claim 1 wherein a gradient is estimated for each pixel of the model after applying a noise filter to the image.

10. The method according to claim 1 wherein the detection process includes using a finite differences process.

11. The method according to claim 1 wherein the detection process includes:

after calculating the gradients, identifying and marking an image point as an edge point having a locally maximal gradient in the direction of the gradient that exceeds a threshold;

identifying neighboring edge points by finding nearest pixels to the original edge point that lie in a direction that is approximately perpendicular to the gradient direction that passes through the first edge point;

for the nearest pixels, determining gradient values and, for the pixel with a gradient that is maximal along its gradient direction and has a value that exceeds a threshold, assigning the pixel to be the next edge point;

continuing either until the edge is terminated or the edge closes with itself to form a continuous curve;

terminating the process at the previously determined edge point if the gradient of the candidate edge point is less than the threshold; and

repeating the process until all potential edge points have been considered.

12. The method according to claim 1 further including automatically distinguishing biometric features from noise.

13. The method according to claim 12 further including characterizing the noise as a biometric feature that is below a minimum width or extends less than a minimum distance.

14. The method according to claim 1 further including supporting manual editing of features and selecting features that must be present for a successful match.

15. The method according to claim 1 wherein modeling includes modeling at least one region of the image of the at least one portion of the biometric.

16. The method according to claim 15 wherein modeling includes overlapping portions of multiple regions.

17. The method according to claim 15 wherein modeling includes allowing a user to add, extend, or delete features.

18. The method according to claim 15 wherein modeling includes allowing a user to identify features that must be present for a match.

19. The method according to claim 15 wherein modeling includes allowing the user to adjust the size or position of the model relative to the biometric.

20. The method according to claim 1 wherein the image is a previously stored image; and modeling includes normalizing a size of the image as a function of a scale associated with the image.

21. The method according to claim 1 wherein the biometric is an area of skin with a friction ridge pattern and the features include ridge structure with ridge deviation detail.

22. The method according to claim 1 further including displaying the image to a user with an overlay of indications of the biometric features of the image.

23. The method according to claim 1 further including displaying the image to a user with an overlay of indications of filtered biometric features according to a selectable criteria.

24. The method according to claim 1 further including automatically rotating the image to a specified orientation for displaying to a user.

25. The method according to claim 1 wherein the image is a gray-scale image.

26. The method according to claim 1 further including adding the image of the at least a portion of the biometric to a database.

27. The method according to claim 26 wherein adding the image includes storing the image and the model of the image in the database.

28. The method according to claim 26 wherein adding the image includes storing the image at full sampled resolution.

29. The method according to claim 26 wherein adding the image includes compressing the data representing the image prior to storing in the database.

30. The method according to claim 29 wherein compressing the image includes compressing the image in a lossless manner.

31. The method according to claim 26 wherein adding the image includes compressing the model prior to storing the image in the database.

32. The method according to claim 26 wherein adding the image includes encrypting the data or model prior to storing the image in the database.

33. The method according to claim 26 wherein adding the image includes storing the image and the model of the at least a portion of the biometric with associated information.

34. The method according to claim 33 wherein the associated information includes at least one of: identity of a person associated with the biometric; manufacturer, model, or serial number of the instrument supplying the data representing the portion of the biometric; date of biometric imaging; time of day of biometric imaging; calibration data associated with the instrument used to acquire the image; temperature at the time the image was acquired; unique computer ID receiving the data representing the image from the instrument acquiring the image of the biometric; or name of person logged into the computer at the time the image was acquired.

35. The method according to claim 33 wherein the associated information includes a photograph, voice recording, or signature of the person whose biometric is imaged.

36. The method according to claim 33 wherein the associated information is a watermark.

37. The method according to claim 36 wherein the watermark is identifying information.

38. The method according to claim 36 wherein the watermark includes anti-tampering information.

39. The method according to claim 1 further including comparing a previously stored model from a database to a present image.

40. The method according to claim 39 wherein the present image is at least a portion of a biometric of a person having a known identity.

41. The method according to claim 39 wherein the present image is at least a portion of a biometric of a person having an unknown identity.

42. The method according to claim 39 wherein the present image is received from one of the following sources: live source, local database, scanned image, or other source.

43. The method according to claim 39 wherein comparing includes comparing outline features of the previously stored model to outline features of the present image to determine (i) whether the present image is a candidate for a match or (ii) whether the previously stored model is a candidate for a match.

44. The method according to claim 43 wherein comparing includes determining whether the comparison exceeds a predetermined candidate threshold.

45. The method according to claim 43 wherein, if the present image is not a candidate for a match, comparing includes comparing outline features of another previously stored model to the outline features of the present image to determine whether the present image is a candidate for a match and if so, using the next previously stored model for details comparison.

46. The method according to claim 43 wherein, if the previously stored model is not a candidate for a match, comparing includes comparing outline features of a next previously stored model to the outline features of the present image to determine whether the next previously stored model is a candidate for a match and if so, using the next previously stored model for details comparison.

47. The method according to claim 43 wherein, if a candidate match of outline features is found, comparing includes comparing details features of the previously stored model with details features of the present image.

48. The method according to claim 47 wherein comparing details features includes determining whether the details comparison exceeds a predetermined threshold.

49. The method according to claim 47 wherein comparing details features includes determining whether required features associated with the previously stored model are found in the present image.

50. The method according to claim 47 wherein the biometric is an area of skin with a friction ridge pattern and wherein comparing includes comparing fine details features, wherein comparing fine details features includes determining whether pore features in the previously stored model are found in the present image.

51. The method according to claim 50 further including indicating which pores in the previously stored model appear in expected locations in the present image, including allowing for distortions that normally occur between successive impressions.

52. The method according to claim 51 further indicating a pore count or a statistical probability of an error in at least cases allowing for distortions.

53. The method according to claim 47 wherein comparing details features includes determining whether the details comparison exceeds a predetermined threshold a specified number of consecutive frames.

54. The method according to claim 53 wherein the details features in successive frames are different.

55. The method according to claim 53 further including selecting another details feature set of the previously stored model for correlating with another details feature set of the present image.

56. The method according to claim 53 further including: (i) selecting another previously stored model for correlating with a features set of the present image and (ii) declaring a successful match if any model exceeds a predetermined threshold.

57. The method according to claim 39 wherein comparing includes comparing outline features of the previously stored model to outline features of a model of the present image and, if the comparison exceeds a predetermined threshold, comparing details features of the previously stored model to details features of the model of the present image to determine whether the previously stored model and the present image match.

58. The method according to claim 39 wherein comparing includes scaling the previously stored model, present image, or model of the present image.

59. The method according to claim 39 wherein comparing includes rotating the previously stored model, present image, or present model.

60. The method according to claim 39 wherein comparing includes adaptively conforming the previously stored model to account for variability associated with recording or acquiring the present image.

61. The method according to claim 60 wherein accounting for variability includes accounting for an expected location of predefined features.

62. The method according to claim 60 wherein the variability includes stretching of the biometric or portions thereof laterally, longitudinally, or radially.

63. The method according to claim 60 wherein the variability is caused by pressure of the biometric on a medium used to record or acquire the present image.

64. The method according to claim 39 wherein comparing includes comparing the previously stored model against multiple present images until a match is found or comparison with the multiple present images is complete.

65. The method according to claim 39 wherein comparing includes comparing multiple previously stored models against the present image until a match is found or comparison with the multiple previously stored models is complete.

66. The method according to claim 39 wherein comparing includes comparing multiple previously stored models against multiple present images until comparing against the multiple previously stored models is complete.

67. The method according to claim 39 wherein the present image includes multiple biometrics of an individual.

68. The method according to claim 39 wherein the multiple biometrics are different areas of skin with a friction ridge pattern from the same individual.

69. The method according to claim 1 further including comparing previously stored models of multiple biometrics to present images of multiple, respective biometrics.

70. The method according to claim 69 further including determining a combined metric based on the comparisons.

71. The method according to claim 1 further including preprocessing the data representing the image.

72. The method according to claim 71 further including subsampling the at least a portion of the biometric to produce the data representing the image.

73. The method according to claim 71 wherein preprocessing includes decimating the data representing the image.

74. The method according to claim 71 wherein preprocessing includes binning the data representing the image.

75. The method according to claim 71 wherein preprocessing includes correcting for uneven imaging of the at least a portion of the biometric.

76. The method according to claim 71 wherein preprocessing includes accounting for defective pixels of an instrument used to acquire the at least a portion of the biometrics.

77. The method according to claim 71 wherein preprocessing includes encrypting the data representing the image.

78. The method according to claim 71 wherein preprocessing includes changing the image orientation, including changing the image orientation by flipping the image vertically or horizontally or by rotating the image.

79. The method according to claim 71 wherein preprocessing includes attaching sensor information to the data representing the image.

80. The method according to claim 71 wherein preprocessing includes applying a watermark to the data representing the image.

81. The method according to claim 80 wherein the watermark includes information used for tamper-proofing the image to allow for identifying a modified image or modified information associated with the image.

82. An apparatus for processing an image of a biometric, comprising:
a gradient edge detector that detects features in a biometric based on data representing an image of at least a portion of the biometric; and
a modeler that models the image as a function of the features.

83. The apparatus according to claim 82 wherein the modeler constructs the model for at least two resolutions.

84. The apparatus according to claim 83 wherein the resolutions include an outline model at a low resolution and a details model at a high resolution

85. The apparatus according to claim 84 wherein the biometric is an area of skin, with a friction ridge pattern and the outline model includes edge topology of ridge features, and the details model includes edge topology and specifics of ridge deviations and locations and sizes of pores.

86. The apparatus according to claim 83 wherein the resolutions include an outline model at a low resolution, a details model at a high resolution, and a fine details model used to locate and define particular biometric features more accurately than at the low or high resolutions.

87. The apparatus according to claim 83 wherein the biometric is an area of skin with a friction ridge pattern and the modeler includes an identifier, outliner, and extractor to determine ridge deviation detail and pore features.

88. The apparatus according to claim 87 wherein the ridge deviation detail includes ridge contours including scars; and the pore features include position, shape, and sizes of pores.

89. The apparatus according to claim 83 wherein the biometric includes at least one of the following: ear shape and structure, facial or hand thermograms, iris or retina structure, handwriting, fingerprints, palm prints, or toe prints.

90. The apparatus according to claim 82 wherein a gradient is estimated for each pixel of the model after applying a noise filter to the image.

91. The apparatus according to claim 82 wherein the detector includes a finite differences processor.

92. The apparatus according to claim 82 wherein the detector:

after calculating the gradients, identifies and marks an image point as an edge point having a locally maximal gradient in the direction of the gradient that exceeds a threshold value;

identifies neighboring edge points by finding nearest pixels to the original edge point that lie in a direction that is approximately perpendicular to the gradient direction that passes through the first edge point;

for the nearest pixels, determines gradient values and, for the pixel with a gradient that is maximal along its gradient direction and has a value that exceeds a threshold, assigns the pixel to be the next edge point;

continues either until the edge is terminated or the edge closes with itself to form a continuous curve;

terminates the process at the previously determined edge point if the gradient of the candidate edge point is less than the threshold; and

repeats the process until all potential edge points have been considered.

93. The apparatus according to claim 82 wherein the detector automatically distinguishes biometric features from noise.

94. The apparatus according to claim 93 wherein the detector characterizes noise as a biometric feature that is below a minimum width or extends less than a minimum distance.

95. The apparatus according to claim 82 further including a manual editing mechanism in communication with the detector to support manual editing of features and selecting of features that must be present for a successful match.

96. The apparatus according to claim 82 wherein the modeler models at least one region of the image of the at least one portion of the biometric.

97. The apparatus according to claim 96 wherein the modeler models overlapping portions of multiple regions.

98. The apparatus according to claim 96 wherein the modeler allows a user to add, extend, or delete features.

99. The apparatus according to claim 96 wherein the modeler allows a user to identify features that must be present for a match.

100. The apparatus according to claim 96 wherein the modeler allows the user to adjust the size or position of the model relative to the biometric.

101. The apparatus according to claim 82 wherein the image is a previously stored image; and the modeler normalizes a size of the image as a function of a scale associated with the image.

102. The apparatus according to claim 82 wherein the biometric is an area of skin with a friction ridge pattern and the features include ridge structure with ridge deviation detail.

103 The apparatus according to claim 71 further including a display in communication with the modeler that displays the image to a user with an overlay of indications of the biometric features of the image.

104. The apparatus according to claim 71 further including a display in communication with the modeler that displays the image to a user with an overlay of indications of filtered biometric features according to a selectable criteria.

105. The apparatus according to claim 82 further including an image manipulator that automatically rotates the image to a specified orientation for displaying to a user.

106. The apparatus according to claim 82 wherein the image is a gray-scale image.

107. The apparatus according to claim 82 further including a database that stores the image of the at least a portion of the biometric.

108. The apparatus according to claim 107 wherein the database stores the image and the model of the image.

109. The apparatus according to claim 107 wherein the database stores the image at full sampled resolution.

110. The apparatus according to claim 107 further including a compressor that compresses the data representing the image prior to storing in the database.

111. The apparatus according to claim 110 wherein the compressor compresses the image in a lossless manner.

112. The apparatus according to claim 107 wherein the compressor compresses the model prior to storing the image in the database.

113. The apparatus according to claim 107 further including an encryption unit that encrypts the data or model prior to storing the image in the database.

114. The apparatus according to claim 107 wherein the database stores the image and the model of the at least a portion of the biometric with associated information.

115. The apparatus according to claim 114 wherein the associated information includes at least one of: identity of a person associated with the biometric; manufacturer, model, or serial number of the instrument supplying the data representing the portion of the biometric; date of imaging the biometric; time of day of imaging the biometric; calibration data associated with the instrument used to acquire the image; temperature at the time of acquiring the image; photograph, voice recording, or signature of the person whose biometric is imaged; watermark; unique computer ID of the computer receiving the data representing the image from the instrument acquiring the image of the biometric; or name of person logged into the computer at the time of acquiring the image.

116. The apparatus according to claim 114 wherein the associated information includes a photograph, voice recording, or signature of the person whose biometric is imaged.

117. The apparatus according to claim 114 wherein the associated information is a watermark.

118. The apparatus according to claim 117 wherein the watermark is identifying information.

119. The apparatus according to claim 117 wherein the watermark includes anti-tampering information.

120. The apparatus according to claim 82 further including an input unit that provides a present image, a database that stores previously acquired images and associated models, and a compare unit that compares a previously stored model from a database to a present image.

121. The apparatus according to claim 120 wherein the present image is at least a portion of a biometric of a person having a known identity.

122. The apparatus according to claim 120 wherein the present image is at least a portion of a biometric of a person having an unknown identity.

123. The apparatus according to claim 120 wherein the present image is received from one of the following sources: live source, local database, image scanner, or other source.

124. The apparatus according to claim 120 wherein the compare unit compares outline features of the previously stored model to outline features of the present image to determine (i) whether the present image is a candidate for a match or (ii) whether the previously stored model is a candidate for a match.

125. The apparatus according to claim 124 wherein the compare unit determines whether the comparison exceeds a predetermined candidate threshold.

126. The apparatus according to claim 124 wherein, if the present image is not a candidate for a match, the compare unit compares outline features of a next previously stored model to the outline features of the present image to

determine whether the present image is a candidate for a match and if so, uses the next previously stored model for details comparison.

127. The apparatus according to claim 124 wherein, if the previously stored model is not a candidate for a match, the compare unit compares outline features of a next previously stored model to the outline features of the present image to determine whether the next previously stored model is a candidate for a match and if so, uses the next previously stored model for details comparison.

128. The apparatus according to claim 124 wherein, if a candidate match of outline features is found, the compare unit compares details features of the previously stored model with details features of the present image.

129. The apparatus according to claim 128 wherein the compare unit further determines whether the details comparison exceeds a predetermined threshold.

130. The apparatus according to claim 128 wherein the comparison unit further determines whether required features associated with the previously stored model are found in the present image.

131. The apparatus according to claim 128 wherein the biometric is an area of skin with a friction ridge pattern and the comparison unit compares details features, wherein the comparison unit determines whether pore features in the previously stored model are found in the present image.

132. The apparatus according to claim 131 wherein the detector indicates which pores in the previously stored model appear in expected locations in the present image, the detector allowing for distortions that normally occur between successive impressions.

133. The apparatus according to claim 132 wherein the detector further indicates a pore count or a statistical probability of an error in at least cases allowing for distortion.

134. The apparatus according to claim 128 wherein the comparison unit further determines whether the details comparison exceeds a predetermined threshold a specified number of consecutive frames.

135. The apparatus according to claim 134 wherein the details features in successive frames are different.

136. The apparatus according to claim 134 wherein the comparison unit selects another details feature set of the previously stored model for correlating with another details feature set of the present image.

137. The apparatus according to claim 134 wherein the comparison unit (i) selects another previously stored model for correlating with a feature set of the present image and (ii) declares a successful match if any model exceeds a predetermined threshold.

138. The apparatus according to claim 120 wherein the comparison units compares outline features of the previously stored model to outline features of a model of the present image and, if the comparison exceeds a predetermined threshold, compares details features of the previously stored model to details features of the model of the present image to determine whether the previously stored model and the present image match.

139. The apparatus according to claim 120 wherein the comparison unit scales the previously stored model, present image, or model of the present image.

140. The apparatus according to claim 120 wherein the comparison unit rotates the previously stored model, present image, or present model.

141. The apparatus according to claim 120 wherein the comparison unit adaptively conforms the previously stored model to account for variability associated with recording or acquiring the present image.

142. The apparatus according to claim 141 wherein the comparison unit accounts for variability by accounting for an expected location of predefined features.

143. The apparatus according to claim 141 wherein the variability includes stretching of the biometric or portions thereof laterally, longitudinally, or radially.

144. The apparatus according to claim 141 wherein the variability is caused by pressure of the biometric on a medium used to record or acquire the present image.

145. The apparatus according to claim 120 wherein the comparison unit compares the previously stored model against multiple present images until a match is found or comparison with the multiple present images is complete.

146. The apparatus according to claim 120 wherein the comparison unit compares multiple previously stored models against the present image until a match is found or comparison with the multiple previously stored models is complete.

147. The apparatus according to claim 120 wherein the comparison unit compares multiple previously stored models against multiple present images until comparing the multiple previously stored models is complete.

148. The apparatus according to claim 120 wherein the present image includes multiple areas of skin with a friction ridge pattern of an individual.

149. The apparatus according to claim 120 wherein the multiple biometrics are different areas of skin with a friction ridge pattern from the same individual.

150 The apparatus according to claim 82 further including a comparison unit that compares previously stored models of multiple biometrics to present images of multiple, respective biometrics.

151. The apparatus according to claim 150 wherein the comparison unit further determines a combined metric based on the comparisons.

152. The apparatus according to claim 82 further including a preprocessor in communication with the detector that preprocesses the data representing the image.

153. The apparatus according to claim 152 wherein the preprocessor subsamples the at least a portion of the biometric to produce the data representing the image.

154. The apparatus according to claim 152 wherein the preprocessor decimates the data representing the image.

155. The apparatus according to claim 152 wherein the preprocessor bins the data representing the image.

156. The apparatus according to claim 152 wherein the preprocessor corrects for uneven imaging of the at least a portion of the biometric.

157. The apparatus according to claim 152 wherein the preprocessor accounts for defective pixels of an instrument used to acquire the at least a portion of the biometric.

158. The apparatus according to claim 152 wherein the preprocessor encrypts the data representing the image.

159. The apparatus according to claim 152 wherein the preprocessor changes the image orientation by flipping the image vertically or horizontally or by rotating the image.

160. The apparatus according to claim 152 wherein the preprocessor attaches sensor information to the data representing the image.

161. The apparatus according to claim 152 wherein the preprocessor applies a watermark to the data representing the image.

162. The apparatus according to claim 161 wherein the watermark includes information used for tamper-proofing the image to allow for identifying a modified image or modified information associated with the image.

163. An apparatus for processing an image of a biometric, comprising:

gradient edge detection means for detecting features in a biometric based on data representing an image of at least a portion of the biometric; and

means for modeling the image as a function of the features.

164. A method for processing an image of a biometric, comprising:

acquiring data representing an image of at least a portion of a biometric; and

modeling features of the biometric for at least two resolutions.

165. The method according to claim 164 wherein the resolutions include an outline model at a low resolution, a details model at a high resolution, and a fine details model used to locate and define particular biometric features more accurately than at low or high resolutions.

166. The method according to claim 164 wherein the biometric is an area of skin with a friction ridge pattern, the outline model includes edge topology of ridge features, and the details model includes edge topology and specifics of ridge deviations and locations and sizes of pores.

167. The method according to claim 164 wherein modeling the image includes applying a gradient edge detection process.

168. The method according to claim 164 wherein the biometric includes at least one of the following: ear shape and structure, facial or hand thermograms, iris or retina structure, handwriting, fingerprints, palm prints, foot prints,or toe prints.

169. The method according to claim 164 further including storing the image and model in a database with associated information, including at least one of the following: identity of a person associated with the biometric; manufacturer, model, or serial number of the instrument supplying the data representing the portion of the biometric; date of imaging the biometric; time day of imaging the biometric; calibration data associated with the instrument used to acquire the image; temperature at the time of acquiring the image; photograph, voice recording, or signature of the person whose biometric is imaged; watermark; unique computer ID of the computer receiving the data representing the image of the biometric; or name of person logged into the computer at the time of acquiring the image.

170. The method according to claim 164 further including comparing a previously stored model from a database to a present image.

171. The method according to claim 170 wherein the present image is at least a portion of a biometric of a person having a known identity or having an unknown identity.

172. The method according to claim 170 wherein, if a candidate match of outline features is found, the method further includes comparing details features of the previously stored model with details features of the present image.

173. The method according to claim 170wherein the comparing includes adaptively conforming the previously stored model to account for variability associated with recording or acquiring the present image.

174. The method according to claim 164 further including preprocessing the data, wherein the preprocessing includes at least one of the following:

subsampling the at least a portion of the biometric to produce the data representing the image;

decimating the data representing the image;

binning the data representing the image;

correcting for uneven imaging of the at least a portion of the biometric;

accounting for defective pixels of an instrument used to acquire the at least a portion of the biometric;

encrypting the data representing the image;

changing the image orientation by flipping the image vertically or horizontally or by rotating the image;

attaching sensor information to the data representing the image; or

applying a watermark to the data representing the image.

175. An apparatus for processing an image of a biometric, comprising:

a data acquisition unit that acquires data representing an image of at least a portion of a biometric; and

a modeler that models features of the biometric for at least two resolutions.

176. The apparatus according to claim 175 wherein the resolutions include an outline model at a low resolution, a details model at a high resolution, and a fine details model used to locate and define particular biometric features more accurately than at low or high resolutions.

177. The apparatus according to claim 176 wherein the biometric is an area of skin with a friction ridge pattern, the outline model includes edge topology of ridge features, and the details model includes edge topology and specifics of ridge deviations and locations and sizes of pores.

178. The apparatus according to claim 175 wherein the modeler includes a gradient edge detector to detect biometric features in the image.

179. The apparatus according to claim 175 wherein the biometric includes at least one of the following: ear shape and structure, facial or hand thermograms, iris or retina structure, handwriting, fingerprints, palm prints, or toe prints.

180. The apparatus according to claim 175 further including a database that stores the image and model with associated information, including at least one of: identity of a person associated with the biometric; manufacturer, model, or serial number of the instrument supplying the data representing the portion of the biometric, date of imaging the biometric; time of day of imaging the biometric; calibration data associated with the instrument used to acquire the image; temperature at the time of acquiring the image; photograph, voice recording, or signature of the person whose biometric is imaged; watermark; unique computer ID of the computer receiving the data representing the image from the instrument acquiring the image of the biometric; or name of person logged into the computer at the time of acquiring the image.

181. The apparatus according to claim 175 further including a comparison unit that compares a previously stored model from a database to a present image.

182. The apparatus according to claim 181 wherein the present image is at least a portion of a biometric of a person having a known identity or having an unknown identity.

183. The apparatus according to claim 181 wherein, if a candidate match of outline features is found, the comparison unit compares details features of the previously stored model with details features of the present image.

184. The apparatus according to claim 181 wherein the comparison unit adaptively conforms the previously stored model to account for variability associated with recording or acquiring the present image.

185. The method according to claim 175, further including a preprocessor that preprocesses the data, the preprocessor including at least one of the following components:

a subsampler that subsamples the at least a portion of the biometric to produce the data representing the image;

a decimator that decimates the data representing the image;

a binning unit that bins the data representing the image;

a field flattener that corrects for uneven imaging of the at least a portion of the biometric;

a defective pixel correction unit that accounts for defective pixels of an instrument used to acquire the at least a portion of the biometric;

an encryption unit that encrypts the data representing the image;

an image orientation unit that changes the orientation by flipping the image vertically or horizontally or by rotating the image;

a sensor data application unit that attaches sensor information to the data representing the image; or

a watermark application unit that applies a watermark to the data representing the image.

186. A method for processing an image of a biometric, comprising:

means for acquiring data representing an image of at least a portion of a biometric; and

means for modeling features of the biometric for at least two resolutions.

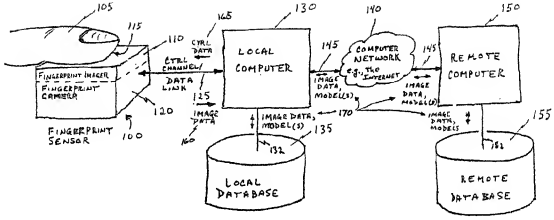

105
115
110
CTRL DATA
CTRL CHANNEL
DATA LINK
125
FINGERPRINT IMAGER
FINGERPRINT CAMERA
120
IMAGE DATA
FINGERPRINT SENSOR
100
160
165
130
LOCAL COMPUTER
IMAGE DATA, MODEL(S)
135
132
LOCAL DATABASE
140
COMPUTER NETWORK
e.g., the Internet
145
145
IMAGE DATA, MODEL(S)
170
150
REMOTE COMPUTER
IMAGE DATA, MODELS
155
151
REMOTE DATABASE

FIG. 1

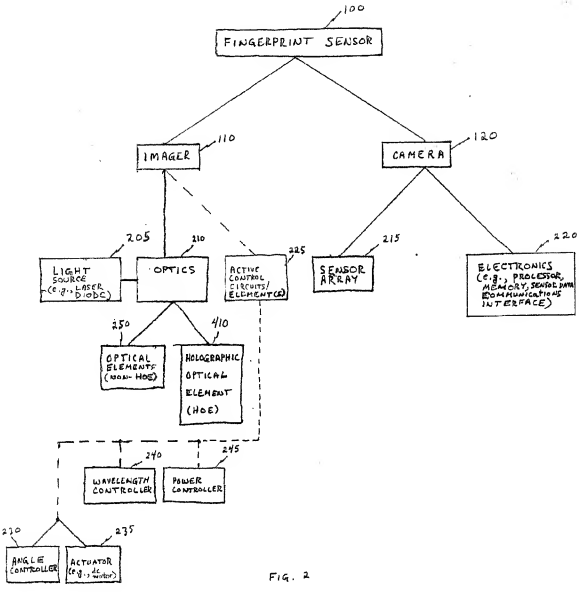

100
FINGERPRINT SENSOR
IMAGER
110
CAMERA
120
205
LIGHT SOURCE (e.g., LASER DIODE)
210
OPTICS
225
ACTIVE CONTROL CIRCUITS/ ELEMENT(S)
215
SENSOR ARRAY
220
ELECTRONICS (e.g., PROCESSOR, MEMORY, SIGNAL PATH, COMMUNICATIONS INTERFACE)
250
OPTICAL ELEMENT(S) (NON-HOE)
410
HOLOGRAPHIC OPTICAL ELEMENT (HOE)
240
WAVELENGTH CONTROLLER
245
POWER CONTROLLER
230
ANGLE CONTROLLER
235
ACTUATOR (e.g., ZIP MOTOR)

FIG. 2

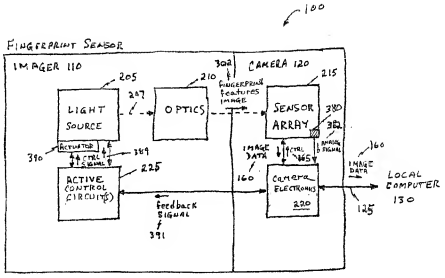

100
FINGERPRINT SENSOR
IMAGER 110
205
LIGHT SOURCE
207
210
OPTICS
302
FINGERPRINT FEATURES IMAGE
CAMERA 120
215
SENSOR ARRAY
380
382
390
ACTUATOR
389
225
ACTIVE CONTROL CIRCUIT(S)
IMAGE DATA
160
CONTROL SIGNAL
365
CAMERA ELECTRONICS
220
160
IMAGE DATA
LOCAL COMPUTER
150
125
feedback SIGNAL
391

FIG. 3A

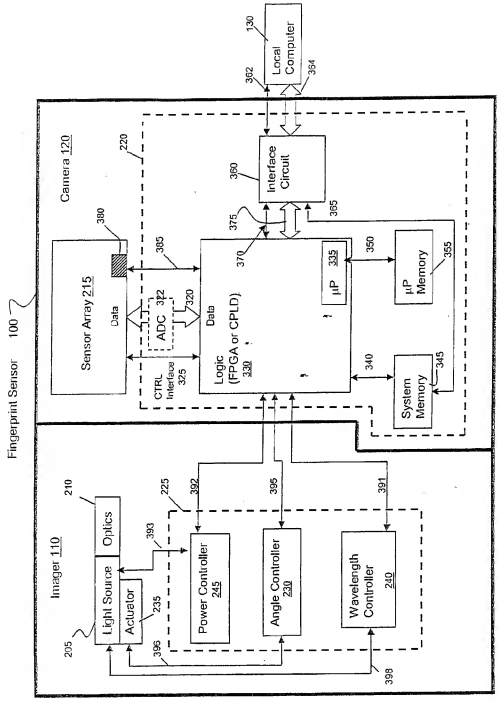

Fingerprint Sensor 100
Imager 110
Light Source 205
Optics 210
Actuator 235
Power Controller 245
Angle Controller 230
Wavelength Controller 240
Camera 120
Sensor Array 215
Data
ADC 322
CTRL Interface 375
Logic (FPGA or CPLD) 330
μP 335
μP Memory 355
System Memory 345
Interface Circuit 360
Local Computer 130
380
385
370
375
365
350
340
362
364
220
225
392
395
391
393
396
398

Figure 3B

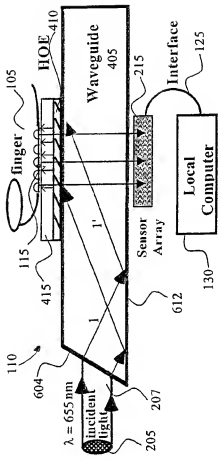

finger
105
HOE
410
Waveguide
405
215
Interface
125
115
415
1'
Sensor
Array
612
Local
Computer
130
1
110
604
λ = 655 nm
Incident
light
205
207

FIG. 4

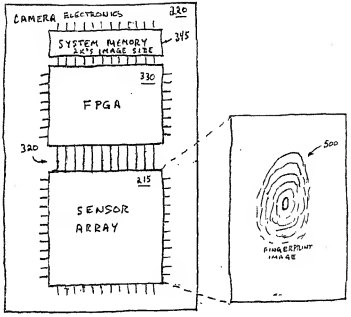

CAMERA ELECTRONICS
220
SYSTEM MEMORY
2K*2 IMAGE SIZE
245
330
FPGA
320
215
SENSOR
ARRAY
500
FINGERPRINT
IMAGE

FIG. 5

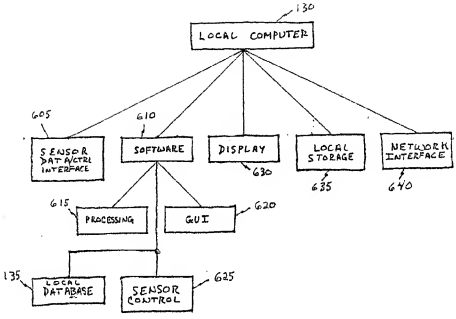

130
LOCAL COMPUTER
605
610
SENSOR DATA/CTRL INTERFACE
SOFTWARE
DISPLAY
630
LOCAL STORAGE
635
NETWORK INTERFACE
640
615
PROCESSING
GUI
620
135
LOCAL DATABASE
SENSOR CONTROL
625

FIG. 6A

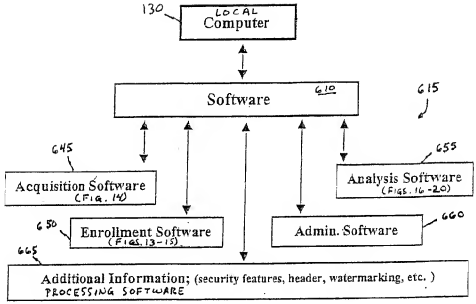

130
LOCAL Computer
Software
610
615
645
Acquisition Software
(FIG. 14)
655
Analysis Software
(FIGS. 16-20)
650
Enrollment Software
(FIGS. 13-15)
660
Admin. Software
665
Additional Information; (security features, header, watermarking, etc.)
PROCESSING SOFTWARE

FIG. 6B

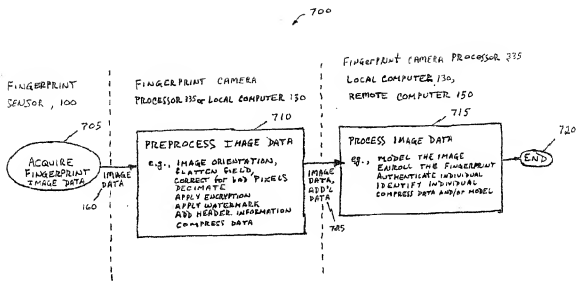

700
FINGERPRINT SENSOR, 100
FINGERPRINT CAMERA PROCESSOR 335 OR LOCAL COMPUTER 130
FINGERPRINT CAMERA PROCESSOR 335
LOCAL COMPUTER 130,
REMOTE COMPUTER 150
705
ACQUIRE FINGERPRINT IMAGE DATA
160
IMAGE DATA
710
PREPROCESS IMAGE DATA
e.g., IMAGE ORIENTATIONS, FLATTEN FIELD, CORRECT FOR BAD PIXELS, DECIMATE, APPLY ENCRYPTION, APPLY WATERMARK, ADD HEADER INFORMATION, COMPRESS DATA
IMAGE DATA, ADD'L DATA
745
715
PROCESS IMAGE DATA
eg., MODEL THE IMAGE, ENROLL THE FINGERPRINT, AUTHENTICATE INDIVIDUAL, IDENTIFY INDIVIDUAL, COMPRESS DATA AND/OR MODEL
720
END

FIG. 7

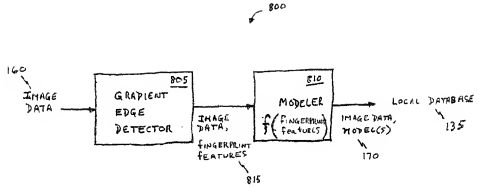

800
160
IMAGE DATA
GRADIENT EDGE DETECTOR
805
IMAGE DATA, FINGERPRINT FEATURES
815
MODELER
810
f(FINGERPRINT FEATURES)
IMAGE DATA, MODEL(S)
170
LOCAL DATABASE
135

FIG. 8

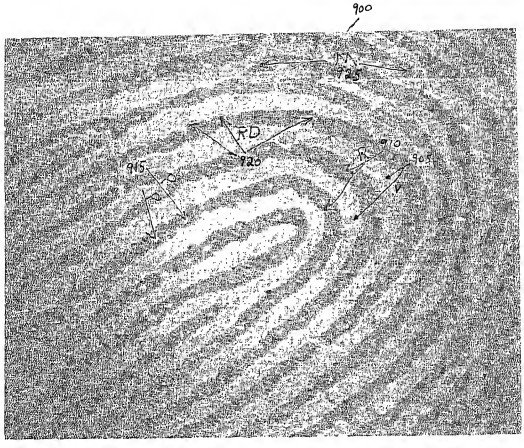


FIG. 9

12 of 24

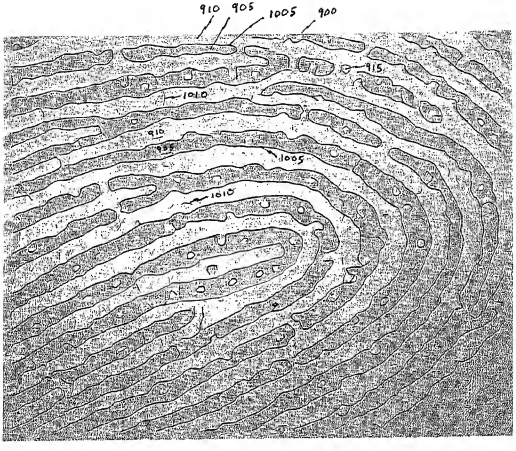


FIG. 10

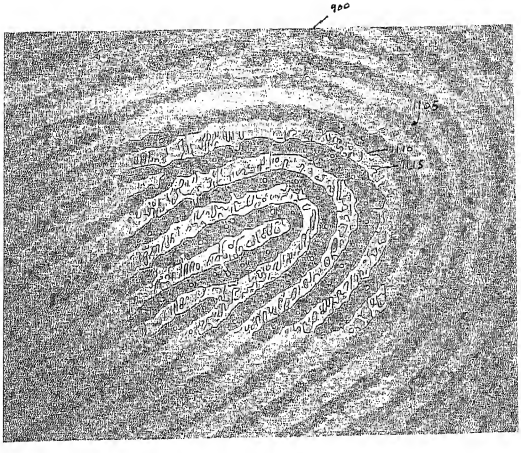


FIG. 11

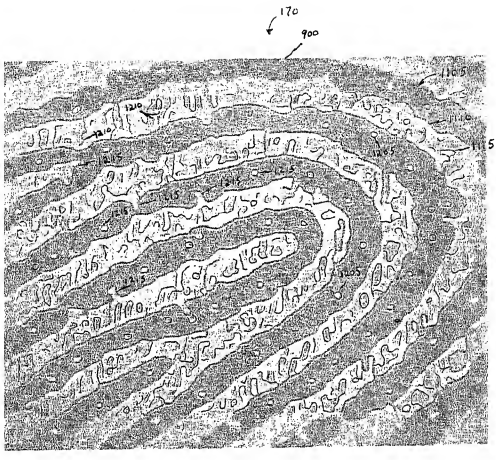


FIG. 12

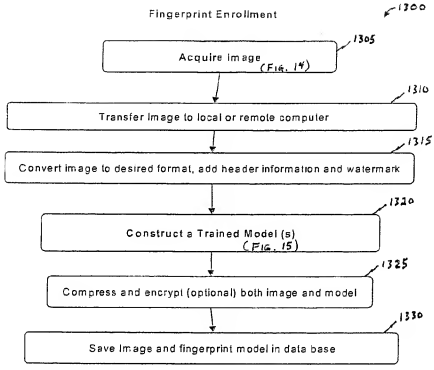

Fingerprint Enrollment
1300
Acquire Image (FIG. 14)
1305
Transfer image to local or remote computer
1310
Convert image to desired format, add header information and watermark
1315
Construct a Trained Model (s) (FIG. 15)
1320
Compress and encrypt (optional) both image and model
1325
Save image and fingerprint model in data base
1330

FIG. 13

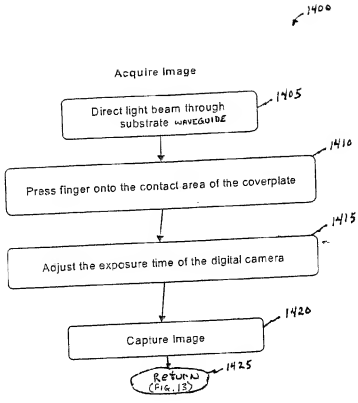

1400
Acquire Image
Direct light beam through substrate WAVEGUIDE
1405
Press finger onto the contact area of the coverplate
1410
Adjust the exposure time of the digital camera
1415
Capture Image
1420
RETURN (FIG. 13)
1425

FIG. 14

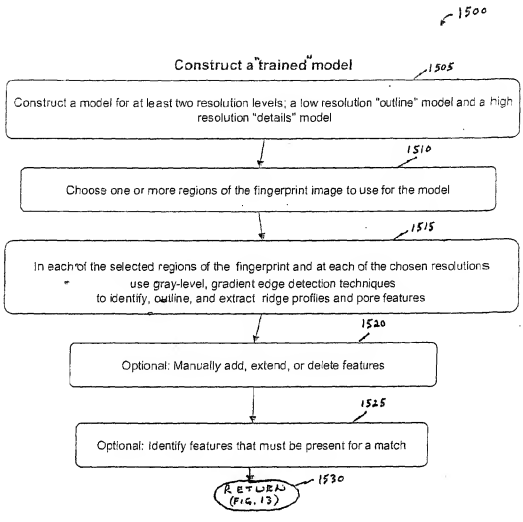

1500
Construct a "trained" model
1505
Construct a model for at least two resolution levels; a low resolution "outline" model and a high resolution "details" model
1510
Choose one or more regions of the fingerprint image to use for the model
1515
In each of the selected regions of the fingerprint and at each of the chosen resolutions use gray-level, gradient edge detection techniques to identify, outline, and extract ridge profiles and pore features
1520
Optional: Manually add, extend, or delete features
1525
Optional: Identify features that must be present for a match
1530
RETURN (FIG. 13)

FIG. 15

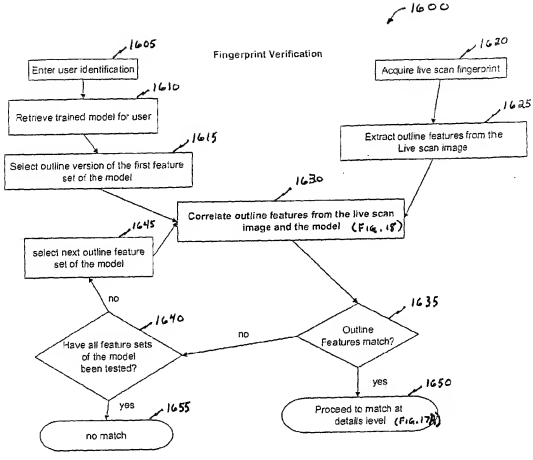

1600
Fingerprint Verification
1605
Enter user identification
1610
Retrieve trained model for user
1615
Select outline version of the first feature set of the model
1620
Acquire live scan fingerprint
1625
Extract outline features from the Live scan image
1630
Correlate outline features from the live scan image and the model (Fig. 18)
1635
Outline Features match?
1640
Have all feature sets of the model been tested?
1645
select next outline feature set of the model
1650
Proceed to match at details level (Fig. 17A)
1655
no match
no
yes
no
yes

Fig. 16

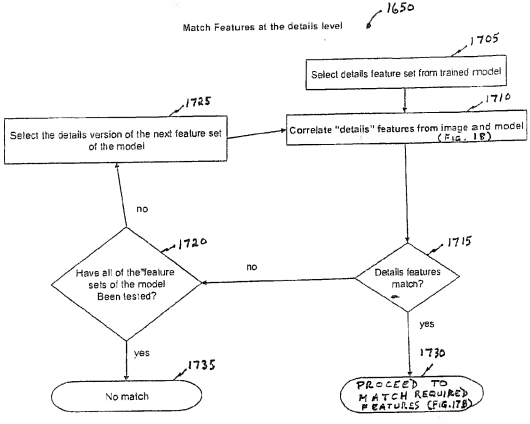

1650
Match Features at the details level
1705
Select details feature set from trained model
1710
Correlate "details" features from image and model (FIG. 18)
1715
Details features match?
1720
Have all of the feature sets of the model Been tested?
1725
Select the details version of the next feature set of the model
1730
PROCEED TO MATCH REQUIRED FEATURES (FIG.17B)
1735
No match
no
yes
no
yes

FIG. 17A

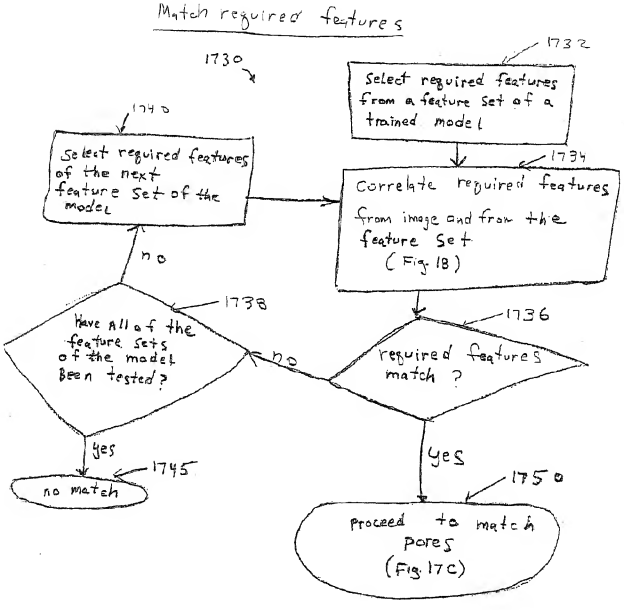

Match required features
1730
1732
Select required features from a feature set of a trained model
1740
Select required features of the next feature set of the model
1734
Correlate required features from image and from the feature set (Fig 18)
no
1738
Have all of the feature sets of the model been tested?
no
1736
required features match ?
yes
1745
no match
yes
1750
Proceed to match pores (Fig 17c)

Fig. 17B

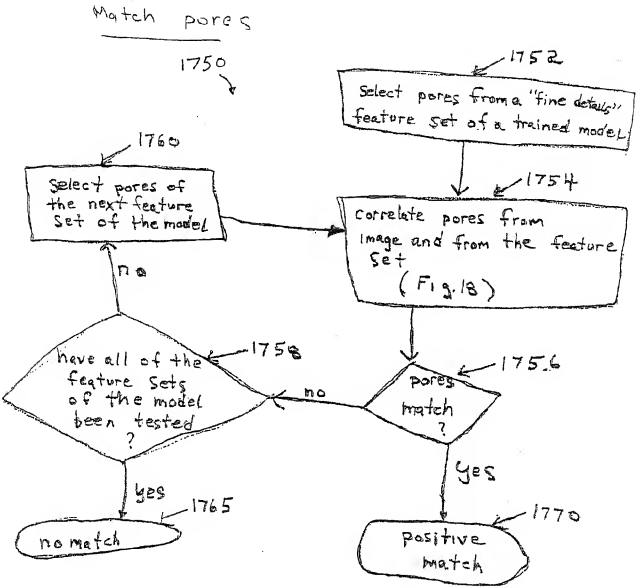

Match pores
1750
1752
Select pores from a "fine details" feature set of a trained model
1754
Correlate pores from image and from the feature set (Fig. 18)
1756
Pores match ?
yes
1770
Positive match
no
1758
have all of the feature sets of the model been tested ?
yes
1765
no match
no
1760
Select pores of the next feature set of the model

Fig. 17C

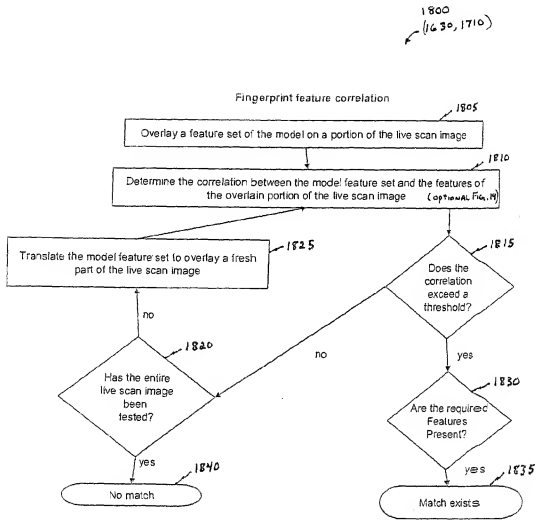

1800
(1430, 1710)
Fingerprint feature correlation
1805
Overlay a feature set of the model on a portion of the live scan image
1810
Determine the correlation between the model feature set and the features of the overlain portion of the live scan image (optional Fig. 19)
1815
Does the correlation exceed a threshold?
no
yes
1820
Has the entire live scan image been tested?
no
yes
1825
Translate the model feature set to overlay a fresh part of the live scan image
1830
Are the required Features Present?
yes
1835
Match exists
1840
No match

FIG. 18

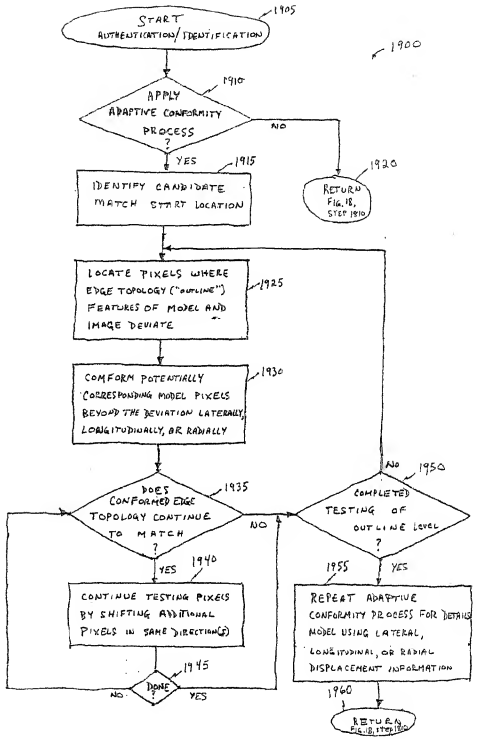

START
AUTHENTICATION/IDENTIFICATION
1905
1900
APPLY ADAPTIVE CONFORMITY PROCESS ?
1910
NO
YES
1915
1920
IDENTIFY CANDIDATE MATCH START LOCATION
RETURN FIG. 18, STEP 1910
LOCATE PIXELS WHERE EDGE TOPOLOGY ("OUTLINE") FEATURES OF MODEL AND IMAGE DEVIATE
1925
CONFORM POTENTIALLY CORRESPONDING MODEL PIXELS BEYOND THE DEVIATION LATERALLY, LONGITUDINALLY, OR RADIALLY
1930
DOES CONFORMED EDGE TOPOLOGY CONTINUE TO MATCH ?
1935
NO
YES
1940
CONTINUE TESTING PIXELS BY SHIFTING ADDITIONAL PIXELS IN SAME DIRECTION(S)
DONE ?
1945
NO
YES
(COMPLETED) TESTING OF OUTLINE LEVEL ?
1950
NO
YES
1955
REPEAT ADAPTIVE CONFORMITY PROCESS FOR DETAILS MODEL USING LATERAL, LONGITUDINAL, OR RADIAL DISPLACEMENT INFORMATION
1960
RETURN FIG. 18, STEP 1910

FIG. 19

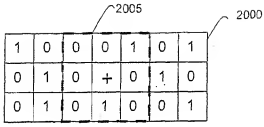


FIG. 20A

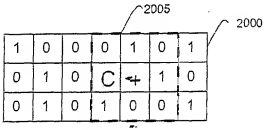


FIG. 20B

EXHIBIT D

Vincent Fedele
P.O. Box 061
Harvard, MA 01451-0061
U.S.A.

JEGP01

27 July, 2006

Beyer Weaver & Thomas, LLP
500 12th Street
Suite 200
Oakland, CA 94607

Subj: **Docket No. 3174.1012-013**

Dear Mr. Egan:

I am in receipt of your letter of 20 July, 2006 regarding the above-mentioned docket.

As you may be aware, I left Aprilis, Inc. on February 03, 2005. One-month prior on or about January 3rd I was provided with assignment and declaration documents by David Waldman for Docket No. 3174.1012-013, and took them immediately to Citizens Bank in Maynard, whose offices are on Nason Street, just outside of the Aprilis location. The documents were signed and notarized, and returned to David Waldman by hand in time to meet the mailing date for this application.

During several conversations with various officers of Aprilis during the week after my departure in February, Aprilis and Mr. Julio Vega, Counsel for Aprilis, confirmed that all assignments and declarations had been properly executed and received by the Company.

Any pertinent prior art, which I may have been aware of during the period I was employed by Aprilis, was disclosed at the time, and I am not aware of any other prior art for 3174.1012-013 since January of 2005.

An email message from Mr. Waldman in April or May of this year referred to several changes and or challenges made by the patent officer reviewing the file(s) that would require changes to one or both of the applications pending review. References to an other patent may also have been included, Docket No. 3174.1013-14. Neither patent application was provided, however, only assignment and declaration pages in Mr. Waldman's email message.

Since the assignment and or declaration documents, as well as your letter include statements that indicate I must read, review and understand the contents of the application(s), and since it has been several years since I have worked on these inventions, I will require at least a day or two to review them, and possibly some time

over the phone with Mr. Waldman. Please clarify if Docket No. 3174.1013-14 is also in need of assignment, declaration and requisite review, as it was not included in your package, but was mentioned in Mr. Waldman's email.

I am happy to provide such review(s), time permitting, as a consultant to the Company, and in accordance with my agreement with the Company which included a provision for compensation for such tasks. I estimate approximately one day, at a minimum, will be required to review the patent application you sent which appears to include more than one hundred claims and some seventy-five pages of text, figures and related documents.

I am planning travel and vacation during the next 2-3 weeks, if I do not hear back from you by August 8th, I will return the document package to your offices.

Regards,

Vincent Fedele

5. Inventions; Assignment.

. . .

(d) At the request of the Company, the Signatory will assist the Company in every proper way (including, without limitation, by executing patent applications) to obtain and enforce in any country in the world Proprietary Rights relating to any or all Assigned Inventions. The Signatory's obligation under this Section 5(d) shall continue after the termination of the Signatory's association with the Company as an employee, consultant, officer or director. If and to the extent that, at any time after the termination of the Signatory's association with the Company as an employee, consultant, officer and/or director, the Company requests assistance from the Signatory with respect to obtaining and enforcing in any country in the world any Proprietary Rights relating to Assigned Inventions, the Company shall compensate the Signatory at a reasonable rate for the time actually spent by the Signatory on such assistance.

EXHIBIT E

UNITED STATES PATENT AND TRADEMARK OFFICE

Commissioner for Patents
United States Patent and Trademark Office
P.O. Box 1450
Alexandria, VA 22313-1450
www.uspto.gov

JJGJR. 02-07

Paper No: __

BEYER WEAVER LLP
P.O. BOX 70250
OAKLAND CA 94612-0250

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MAR 0 2 2007

OFFICE OF PETITIONS

ON PETITION

In re Application of Waldman, et al.
Application No. 10/561,646
Filed: 20 December, 2005
Attorney Docket No. 3174.1012-013

VISGP001

This is a decision on the petition filed on 16 October, 2006, under 37 C.F.R. §1.47.

For the reasons set forth below, the petition under 37 C.F.R. §1.47 is **GRANTED**.

BACKGROUND

The record indicates:

- the instant application was filed on 20 December, 2005, without, *inter alia*, a fully executed oath/declaration;
- on 21 March, 2006, the Office mailed a Notice of Missing Parts indicating, *inter alia*, that a fully executed oath/declaration (signed and dated) was required;
- on 16 October, 2006, Petitioner William J. Egan III (Reg. No. 28,411) filed, *inter alia*, the original petition, an oath/declaration signed by co-inventors Waldman, Ingwall, Raguin, Berg, Joseph and Kent for themselves and on behalf of the nonsigning inventor Vincent Fedele (Mr. Fedele) and an averment, supported by a copy of the transmittal, that the entire application (description, claims, abstract and drawings) as required by statute and regulation, was sent to Mr. Fedele, and an averment as to the reasonably believed to be last known/current mailing address for Mr. Fedele–and while Mr. Fedele's reply of 27 July, 2006, refers to more than one application, it specifically cites the attorney docket

BEYER WEAVER LLP
Received
MAR - 5

number (3174.1012-013) of the instant application and on the second page specifically acknowledges receipt of the instant application.

Out of an abundance of caution, Petitioners always are reminded that those registered to practice *and* all others who make representations before the Office are reminded to inquire into the underlying facts of representations made to the Office and support averments with the appropriate documentation–since all owe to the Office the continuing duty to disclose.[1]

This application and its papers have been reviewed and found in compliance with 37 C.F.R. §1.47(a).

---

[1] See supplement of 17 June, 1999. The Patent and Trademark Office is relying on petitioner's duty of candor and good faith and accepting a statement made by Petitioner. See Changes to Patent Practice and Procedure, 62 Fed. Reg. at 53160 and 53178, 1203 Off. Gaz. Pat. Office at 88 and 103 (responses to comments 64 and 109)(applicant obligated under 37 C.F.R. §10.18 to inquire into the underlying facts and circumstances when providing statements to the Patent and Trademark Office).

Specifically, the regulations at 37 C.F.R. §10.18 provide:

§ 10.18 Signature and certificate for correspondence filed in the Patent and Trademark Office.
(a) For all documents filed in the Office in patent, trademark, and other non-patent matters, except for correspondence that is required to be signed by the applicant or party, each piece of correspondence filed by a practitioner in the Patent and Trademark Office must bear a signature by such practitioner complying with the provisions of §1.4(d), §1.4(e), or § 2.193(c)(1) of this chapter.
(b) By presenting to the Office (whether by signing, filing, submitting, or later advocating) any paper, the party presenting such paper, whether a practitioner or non-practitioner, is certifying that—

(1) All statements made therein of the party's own knowledge are true, all statements made therein on information and belief are believed to be true, and all statements made therein are made with the knowledge that whoever, in any matter within the jurisdiction of the Patent and Trademark Office, knowingly and willfully falsifies, conceals, or covers up by any trick, scheme, or device a material fact, or makes any false, fictitious or fraudulent statements or representations, or makes or uses any false writing or document knowing the same to contain any false, fictitious or fraudulent statement or entry, shall be subject to the penalties set forth under 18 U.S.C. 1001, and that violations of this paragraph may jeopardize the validity of the application or document, or the validity or enforceability of any patent, trademark registration, or certificate resulting therefrom; and

(2) To the best of the party's knowledge, information and belief, formed after an inquiry reasonable under the circumstances, that —

(i) The paper is not being presented for any improper purpose, such as to harass someone or to cause unnecessary delay or needless increase in the cost of prosecution before the Office;

(ii) The claims and other legal contentions therein are warranted by existing law or by a nonfrivolous argument for the extension, modification, or reversal of existing law or the establishment of new law;

(iii) The allegations and other factual contentions have evidentiary support or, if specifically so identified, are likely to have evidentiary support after a reasonable opportunity for further investigation or discovery; and

(iv) The denials of factual contentions are warranted on the evidence, or if specifically so identified, are reasonably based on a lack of information or belief.

(c) Violations of paragraph (b)(1) of this section by a practitioner or non-practitioner may jeopardize the validity of the application or document, or the validity or enforceability of any patent, trademark registration, or certificate resulting therefrom. Violations of any of paragraphs (b)(2)(i) through (iv) of this section are, after notice and reasonable opportunity to respond, subject to such sanctions as deemed appropriate by the Commissioner, or the Commissioner's designee, which may include, but are not limited to, any combination of—

(1) Holding certain facts to have been established;
(2) Returning papers;
(3) Precluding a party from filing a paper, or presenting or contesting an issue;
(4) Imposing a monetary sanction;
(5) Requiring a terminal disclaimer for the period of the delay; or
(6) Terminating the proceedings in the Patent and Trademark Office.

(d) Any practitioner violating the provisions of this section may also be subject to disciplinary action. See § 10.23(c)(15).
[Added 50 FR 5175, Feb. 6, 1985, effective Mar. 8, 1985; para. (a) revised, 58 FR 54494, Oct. 22, 1993, effective Nov. 22, 1993; paras. (a) & (b) revised, paras. (c) & (d) added, 62 FR 53131, Oct. 10, 1997, effective Dec. 1, 1997; para. (a) revised, 69 FR 56481, Sept. 21, 2004, effective Oct. 21, 2004]

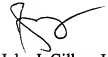
This application hereby is **ACCORDED status under 37 C.F.R. §1.47(a)**.

As provided under 37 C.F.R. §1.47(a), the Office will forward notice of this application's filing to the non-signing inventor at the address given in the petition.

Notice of the filing of this application also will be published in the Official Gazette.

This file is being released to OIPE for processing as necessary to reflect the instant decision before being released for examination in due course.

While telephone inquiries regarding this decision may be directed to the undersigned at (571) 272-3214, it is noted that all practice before the Office is in writing (see: 37 C.F.R. §1.2[2]) and the proper authority for action on any matter in this regard are the statutes (35 U.S.C.), regulations (37 C.F.R.) and the commentary on policy (MPEP). Therefore, no telephone discussion may be controlling or considered authority for Petitioner's/Caller's action(s).



John J. Gillon, Jr.
Senior Attorney
Office of Petitions

[2] The regulations at 37 C.F.R. §1.2 provide:

§1.2 Business to be transacted in writing.

All business with the Patent and Trademark Office should be transacted in writing. The personal attendance of applicants or their attorneys or agents at the Patent and Trademark Office is unnecessary. The action of the Patent and Trademark Office will be based exclusively on the written record in the Office. No attention will be paid to any alleged oral promise, stipulation, or understanding in relation to which there is disagreement or doubt.

UNITED STATES PATENT AND TRADEMARK OFFICE

Commissioner for Patents
United States Patent and Trademark Office
P.O. Box 1450
Alexandria, VA 22313-1450
www.uspto.gov

JJGIR 02-07

Paper No: __

VINCENT FEDELE
P.O. BOX 061
HARVARD, MA 01451

COPY MAILED

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OFFICE OF PETITIONS

In re Application of V1SGP001
Waldman, et al.
Application No. 10/561,646
Filed: 20 December, 2005
Attorney Docket No. 3174.1012-013

COMMUNICATION

Dear Vincent Fedele:

You are named as inventor in the above identified United States patent application, filed under the provisions of 35 U.S.C. §116 (United States Code), and 37 C.F.R. §1.47,[1] ¶a, Rules of Practice in Patent Cases. Should a patent be granted on the application you will be designated therein as inventor.

As a named inventor you are entitled to inspect any paper in the file wrapper of the application, order copies of all or any part thereof (at a prepaid cost per 37 C.F.R. §1.19) or make your position of record in the application. Alternatively, you may arrange to do any of the preceding

[1] The regulations at 37 C.F.R. §1.47 provide:

§ 1.47 Filing when an inventor refuses to sign or cannot be reached.

(a) If a joint inventor refuses to join in an application for patent or cannot be found or reached after diligent effort, the application may be made by the other inventor on behalf of himself or herself and the nonsigning inventor. The oath or declaration in such an application must be accompanied by a petition including proof of the pertinent facts, the fee set forth in §1.17(h), and the last known address of the nonsigning inventor. The nonsigning inventor may subsequently join in the application by filing an oath or declaration complying with §1.63.

(b) Whenever all of the inventors refuse to execute an application for patent, or cannot be found or reached after diligent effort, a person to whom an inventor has assigned or agreed in writing to assign the invention, or who otherwise shows sufficient proprietary interest in the matter justifying such action, may make application for patent on behalf of and as agent for all the inventors. The oath or declaration in such an application must be accompanied by a petition including proof of the pertinent facts, a showing that such action is necessary to preserve the rights of the parties or to prevent irreparable damage, the fee set forth in §1.17(h), and the last known address of all of the inventors. An inventor may subsequently join in the application by filing an oath or declaration complying with §1.63.

© The Office will send notice of the filing of the application to all inventors who have not joined in the application other than [illegible] provided in the petition under this section, and publish notice of the filing of the application in the *Official Gazette*. The Office may dispense with this notice provision in a continuation or divisional application, if notice regarding the filing of the prior application was given to the nonsigning inventor(s).

[47 Fed. Reg. 41275, Sept. 17, 1982, effective Oct. 1, 1982; 48 Fed. Reg. 2709, Jan. 20, 1983, effective Feb. 27, 1983; revised, 62 Fed. Reg. 53131, Oct. 10, 1997, effective Dec. 1, 1997; revised, 65 Fed. Reg. 54604, Sept. 8, 2000, effective Nov. 7, 2000.]

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IN DOCKETING DEPT.
DATE: ____ BY: ____

through a registered patent attorney or agent presenting written authorization from you. If you care to join the application, counsel of record (see below) would presumably assist you. Joining in the application would entail the filing of an appropriate oath or declaration by you pursuant to 37 C.F.R. §1.63.

Requests for information regarding your application should be directed to the File Information Unit at (703) 308-2733.

Information regarding how to pay for and order a copy of the application, or a specific paper in the application, should be directed to Certification Division at (703) 308-9726 or toll-free: (800) 972-6382 (outside the Washington D.C. area).

While telephone inquiries regarding this decision may be directed to the undersigned at (571) 272-3214, it is noted that all practice before the Office is in writing (see: 37 C.F.R. §1.2[2]) and the proper authority for action on any matter in this regard are the statutes (35 U.S.C.), regulations (37 C.F.R.) and the commentary on policy (MPEP). Therefore, no telephone discussion may be controlling or considered authority for Petitioner's/Caller's action(s).

John J. Gillon, Jr.
Senior Attorney
Office of Petitions

Counsel of Record:
BEYER WEAVER LLP
P.O. BOX 70250
OAKLAND CA 94612-0250

[2] The regulations at 37 C.F.R. §1.2 provide:

§1.2 Business to be transacted in writing.

All business with the Patent and Trademark Office should be transacted in writing. The personal attendance of applicants or their attorneys or agents at the Patent and Trademark Office is unnecessary. The action of the Patent and Trademark Office will be based exclusively on the written record in the Office. No attention will be paid to any alleged oral promise, stipulation, or understanding in relation to which there is disagreement or doubt.